Collaborative Ph.D. projects between university and industry : proximity, governance, success

DOI:
10.6100/IR782205

Document status and date:
Published: 01/01/2014

Document Version:
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

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Proximity, Governance, Success

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2014

A catalogue record is available from the Eindhoven University of Technology Library.

ISBN 978-90-8891-964-0

Published by: Proefschriftmaken.nl || Uitgeverij BOXPress

Cover design: Proefschriftmaken.nl || Uitgeverij BOXPress

A note about the cover: The idea behind the cover picture is shaped by Jafar Rezaei. The two intersecting circles on the cover symbolize collaboration between university and industry. This research has been conducted in The Netherlands, the country of tulips. Moreover, the topic of this Ph.D. thesis is about collaboration between a Technical University (TU) and firms, mainly Philips. Therefore, by combining "TU" with "Philips" we made "Tulips", which is a symbol of The Netherlands as well.

Collaborative Ph.D. Projects between University and Industry:
Proximity, Governance, Success

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
rector magnificus prof.dr.ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties, in het openbaar te verdedigen
op donderdag 23 oktober 2014 om 16.00 uur

door

Negin Salimi

geboren te Teheran, Iran

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“Success always calls for greater generosity–though most people, lost in the darkness of their own egos, treat it as an occasion for greater greed. Collecting boot is not an end itself, but only a means for building an empire. Riches would be of little use to us now–except as a means of winning new friends.”

Cyrus the Great

Acknowledgements

A Ph.D. study is a journey that starts from an idea. As a traveller, a Ph.D. candidate is faced with several ups and downs, so at the time of her defence ceremony, she is expected to be prepared to embark upon the main and long journey in the world of science. As a traveller, I would like to take this opportunity to thank all the people who have helped me along my Ph.D. journey, through their support, guidance and encouragement.

I am very grateful to my first promotor, Koen Frenken, who guided my research journey through his valuable advice and criticism, who accelerated my journey through his quick reactions to my challenges, and who gave me courage and inspiration along the way. Koen, your high level of expertise, your true involvement in my research, and your invaluable suggestions are deeply and sincerely appreciated. I have been really fortunate to work under your supervision.

I would like to thank my co-promotor, Rudi Bekkers, for all the time and energy he put into my work. Without his expertise, involvement, and guidance, I would not have been able to complete this dissertation. In our meetings, I learned how to handle challenges from various perspectives and investigate solutions from different angles.

I would like to extend a sincere word of thanks to my second promoter, Sjoerd Romme, for his valuable comments and suggestions to improve my dissertation.

I am also very grateful to Caspar Chorus and Bert van Wee from the Transport and Logistics Group of Delft University of Technology for their warm hospitality and great support during the two last years of my Ph.D. study. During these years I was given several chances to share my research within this group. This atmosphere gave me valuable feedback from colleagues with different backgrounds, which improved my research greatly.

The four years of my Ph.D. study contained hard work and several difficulties. However, some people in particular helped to fill it with a great deal of fun as well. Much of this enjoyment came through conversations with colleagues and friends. I want to especially thank my colleagues and friends at TU/e. Special thanks go to Sadaf Bashir, who has always been kind to me and has supported me in difficult times. I still remember the enjoyment of being together in Strasburg, France, at a Ph.D. workshop, which shaped our friendship very strongly. I would also like to thank my colleagues Yuti Ariani, Johanna Höffken, Suyash Jolly, Lilianne Laan, Carolina Castaldi, Boukje Huijben, Marloes Dignum, and Evelien de Hoop for their encouragement. Many thanks go to the secretaries, Mieke Rompen and Letty Calame for their support and help. I am more thankful to Boukje Huijben and Marloes Dignum for accepting to be my paranimphs and accompanying me on the stage.

I would like to thank my colleagues and friends at TU Delft. Special thanks go to Jan Anne Annema, Roland Ortt, and Victor Scholten for their valuable comments and suggestions on my presentations in the Transport and Logistics group. I would like to thank Diana Vonk Noordegraaf, Özgül Ardıç, Yashar Araghi, Karimah Wan Ahmad, and Nicole Huijts for their insights and friendly conversations.

I also enjoyed the warm and friendly atmosphere of my office. Special thanks go to my roommates, Nilesh Anand, Sriram Bhamidipati, Caroline Jaffe, Maedeh Fasihi, Ahmad Reza Mir Mohammadi, and Andrew Bollinger. I would like to thank the very helpful and kind secretaries, Karin van Duyn-Derwort, Ellen van der Linden, Betty van Koppen, and Eveline Zeegers.

I am lucky to have great friends, who always support and encourage me. Special thanks go to Fatemeh Nikayin and Samira Farahani, whose doors have always been open to me to share my difficult and happy moments.

Last but not least, I would like to dedicate this work to the very special ones in my life. I am particularly indebted to my loving parents, Mohammad Amin and Homa who guided me to where I am today. Dad, thank you for telling me what I am capable of, and for giving me the support that I needed to build a dream to chase after. And thank you for believing that I have the talent to reach my goals. Mom, thank you for showing me how to fight for what I believe in – in life, love, and everything in between. And thank you for giving me the strength to stand up for myself and expect nothing less than the very best. Without each of you, I would be nowhere near the person I am. I am very grateful to my lovely twin sister Negar and her husband Bakhtyar. Negar, the toughest decision in my life was to immigrate to another country and live a thousand kilometers from you, a person who is indeed myself! However, your continuous encouragement, energy, and support have put a lot of hope in my heart and have stimulated me not to give up in difficult times. Your love and support mean the world to me! Bakhtyar, thanks for your inspiration, support, and kindness during my Ph.D. study. Special thanks go to my lovely brother, Armin, for always being ready with a lot of energy and fun, and for being willing to help me and answer my technical questions regarding my laptop and iPhone!

I am very grateful to my loving son, Pedram for his kindness and support. Pedram you are a special gift in my life. You have created a lot of pleasant moments for me. You tried to make and keep me happy on stressful days with your sweet stories and funny jokes. I want to let you know I am so proud of you!

Finally I want to dedicate my work to my husband, my friend, my love, Jafar. On this special event, I want to let you know how special I feel that God has put you in my life! You have always been available to me, and when life was hopeless you gave me new hope. Jafar, your patience, kindness, support, energy, and love are all special gifts which you give me every moment. In my academic life you were my home supervisor and your critical comments on my research taught me how I should think critically in the scientific world. Without your guidance and encouragement I would not have been able to complete this dissertation. I cannot thank you enough for all that you have done for me.

Negin Salimi
May 2014

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1. Introduction

The Truth was a mirror in the hands of God. It fell, and broke into pieces. Everybody took a piece of it, and they looked at it and thought they had the truth. Molana

1.1. Introduction and aims of this study

Today's rapid speed of technological change and high pace of innovation make it more and more difficult for firms to master every relevant area of expertise. Producing all the required knowledge in-house is not always a feasible solution due to high costs and risks. Acquiring ('buying') the required knowledge from an outside party is not satisfactory either, because knowledge is an experienced-based good, hardly suited to market transactions. Because of the limitations of in-house production and market acquisition, firms increasingly engage in inter-organizational research collaborations in order to pool resources, exploit complementary assets, and share the risks inherent to R&D (Teece, 1986).

For firms wanting to improve their innovation capabilities, universities can provide the most interesting collaborative partnerships. Such collaborations not only allow firms to receive knowledge, but also to engage in a two-way exchange of knowledge and insights (Morandi, 2013; Perkmann *et al.,* 2013). What is more, universities are increasingly incentivized by government policies to seek collaboration with firms as an additional source of funding as well as signalling the economic benefits of public investment in university research. At the same time, collaboration is not without its challenges, especially between two organizations that are rather diverse. Collaboration is inherently a costly and risky activity, in which both partners need to invest time, money and resources, all of which could be used for other activities. Therefore, it is clearly vital for both university and industry to maximize the benefits of collaboration by means of effective management and governance (Dodgson, 1991). The literature on the governance of university-industry collaborations is scarce, however, concentrating mostly on the role of technology transfer offices, intellectual property creation, the commercialization of academic knowledge and academic entrepreneurship (Phan and Siegel, 2006; Rothaermel *et al*., 2007; O'Shea *et al*., 2008; Perkmann *et al*., 2013).

This study focuses exclusively on collaborations, highlighting a specific and important type: collaborative Ph.D. projects. While such collaborations are quite common (at Eindhoven University of Technology almost one third of all Ph.D. projects), very few existing studies look at such collaboration (see Chapter 2).

The first aim of this thesis is to address the above gap in the literature by developing a better understanding of what motivates collaborative Ph.D. projects, how universities and their partners govern such collaborations, and to what extent the governance mode affects project success. Due to the contrast in cultures, objectives and incentives between university and industry, the effective governance of complex collaborative projects is difficult, yet probably crucial for success. Until now, no standard approach to governance has evolved. Instead, projects are being managed in various ways, which is why we need to understand the choices underlying the various governance modes, and their effect on project success.

The second aim of this thesis is to study the potentially harmful effects of increasing industry involvement in Ph.D. projects. In particular, concerns have been raised that such collaborative projects, though beneficial for industry, may harm the academic quality of Ph.D. projects and post-Ph.D. academic careers (Nelson, 2004). While some authors argue that collaboration can improve such performance (Gulbrandsen and Smeby, 2005) and others maintain that collaboration can diminish it. Hence, the existing studies do not offer conclusive evidence on the matter.

1.2. Main research question

With the purpose of understanding how collaborative Ph.D. projects between university and industry are best governed and how their performance compares to 'in-house' university Ph.D. projects, this thesis focuses on the following main research question:

How can we explain the various modes of governance of collaborative Ph.D. projects between university and industry, and what factors drive the success of such collaborative projects?

I have broken down the overall research question into three sub-questions:

RQ1. How do universities and industry govern collaborative Ph.D. projects?

RQ2: How do these governance choices impact successful outcomes?

RQ3: How does the output performance of doctoral candidates in collaborative projects differ from their non-collaborative peers?

RQ1 deals with the question *how universities and industry govern collaborative Ph.D. projects*. Here, this study examines the main dimensions of governance as adopted for such projects, and the determinants of these choices. The central question is, in which cases do partners choose shared governance and in which cases do they prefer to opt for centralized governance. A further question is, under what circumstances do industrial partners decide to impose publication restrictions. To this end, the thesis reports on the outcomes of a large-scale survey on collaborative Ph.D. projects at Eindhoven University of Technology.

RQ2 is *how do governance choices impact successful outcomes*.

Here, I investigate to what extent specific governance choices affect the success of collaboration. The key hypothesis is that shared governance structures lead to more successful projects. Also for this reason I make use of the outcomes of the above mentioned survey on collaborative Ph.D. projects.

RQ3 is *how the output performance of doctoral candidates in collaborative Ph.D. projects compares to that of their non-collaborative peers.* Here, my study addresses the concerns that collaborative projects could result in a trade-off in terms of the academic output of Ph.D. work. To underline this issue, my thesis presents the results of a bibliometric study comparing the output performance of Ph.D. candidates who work in collaboration with industry, with that of their non-collaborative peers, in terms of publication and patent output by the candidates during and after the Ph.D. project, and the citations to these documents.

1.3. Research approach

In order to answer the above research questions, this study uses two distinct, original data sets. The first data set has been collected through an extensive survey among 191 former Ph.D. candidates involved in collaborative Ph.D. projects with firms or Public Research Organizations (PROs). The population underlying this sample includes all collaborative projects between Eindhoven University of Technology (TU/e) and a firm or PRO that resulted in a published Ph.D. thesis between the years 2000 and 2011. By including PROs, this study adopts a broad concept of collaboration. In the Netherlands, despite the word ‘public’ in the acronym, PROs obtain funding mainly from private sources (such as contract research for companies), and only a small part from unconditional, public sources. Furthermore, in many instances, their main objective is not necessarily to produce publicly available knowledge, but more often specific knowledge for commercial or state purposes. Consequently, in many ways these organizations resemble companies more than government bodies, or even universities. It is important to realize that this situation is quite different from that in many other countries.

The summaries and prefaces of all the 1783 theses produced between 2000 and 2011 reveal that 496 of them were the result of collaboration with a firm or a PRO. For 408 of these, it was possible to retrieve a current email address of the former Ph.D. candidate, using a variety of approaches. Instead of taking a sample, the full population was approached.

The questionnaire contained 49 questions, and is attached as an Appendix to this thesis. A cover letter outlined the main goals of the survey. Respondents were assured that their answers would be treated as strictly confidential, and no individual case would be traceable from the outcomes of this study. Data acquisition for this first data set took four months (January to April 2012). After sending two reminders I received a total of 191 complete and valid responses, bringing the overall response rate to 47%. Of the received surveys, 103 represented collaborations with firms and 88 represented collaborations with PROs. The data from this survey was used to identify the determinants of governance choices among partners (Chapter 3), and how governance characteristics affect the success of collaboration (Chapter 4). More details on data collection can be found in Chapters 3 and 4.

The second data set concerns bibliometric performance data on doctoral candidates involved in collaborative projects and on a matching set of peers that conducted in-house university projects, in order to compare the performance differences (Chapter 5). Output by Ph.D. candidates was measured in four dimensions: publication, patent, publication citations, and patent citations. The unit of analysis in this study is former Ph.D. candidates who graduated in the period 2000-2005 from all TU/e departments. To compare the performance of the 224 candidates involved in collaborative Ph.D. projects with those conducting in-house university Ph.D. projects, both groups were matched based on the following four criteria: university department, gender, nationality, and year of graduation.

The publication and citation records of former Ph.D. candidates were obtained from the Scopus database. Scopus provides information including the number of publications, and details of the citations each published document has received. Scopus was used because this database covers more peer reviewed journals than other well-known databases such as PubMed and Web of Science (Kulkarni *et al*., 2009). For patent data, this study draws on the Derwent World Patents Index (DWPI) / Derwent DII database, a value-added patent database developed by Thomson Reuters. The significant advantages of this database are that it comprises patent family information, and that patent metadata has been cleaned up and harmonized. Chapter 5 contains more details of the bibliometric data collection.

1.4. Structure of this thesis

This thesis has six chapters in total. After this introductory chapter, the second chapter starts by discussing research collaborations, specifically at Ph.D. level, and introduces the concept of governance. It also provides an overview of the existing literature and at the same time clarifies the boundaries of this study.

Chapters 3 to 5 can be considered the core of this thesis, focusing on the three research questions introduced in Section 1.2 above. Each of these three chapters is self-contained and has been submitted for journal publication.

The third chapter focuses on RQ1 *('how do universities and industry govern their collaborative Ph.D. projects')*, examining governance aspects including decision-making, daily management and disclosure policies. It also investigates the factors that facilitate partners to engage in joint governance (managing and decision-making), as opposed to the situation where only one of the partners (university or its partner) actually governs the project. The empirical data in this chapter comes from the previously mentioned survey.

Chapter 4 focuses on RQ2 (‘*how do governance choices impact successful outcomes’)* and aims to develop a better understanding of the extent to which choices in terms of governance can improve the success rate of collaborations. This chapter proposes a structure which measures the relationship between governance characteristics and success among collaborative Ph.D. projects. This structure sheds new light on the determinants of success of collaborative Ph.D. projects; it addresses an important research gap apparent in existing studies, which barely cover the impact of governance characteristics and how they relate to the success of collaborative Ph.D. projects. By investigating several correlations between governance and success, this study establishes the effects of different aspects of governance on success. Chapter 4 identifies six success measurements for collaborative Ph.D. projects, including how effectively knowledge was transferred from a university to its partner, whether the firm offered the Ph.D. candidate a job after finishing the project, and whether the collaboration between university and firm continued afterwards. Again the data gathered in the afore-mentioned survey was used.

Chapter 5 moves beyond governance and addresses research question RQ3 (‘*how does the output performance of doctoral candidates in* collaborative *projects differ from their non-collaborative peers’).* This part of the study is motivated by concerns that getting involved in collaborative Ph.D. projects might have a negative effect on the academic performance of such projects. Here, performance is not only measured in terms of the quantity and impact of academic publications (see: Nelson, 2004; Gulbrandsen and Smeby, 2005), but also the output in terms of quantity and impact of patents. This chapter is based on bibliometric data from secondary sources, as outlined in the previous section.

The thesis concludes with an overall interpretation of the results, a reflection on the research questions and suggestions for future research. In the concluding chapter, I place particular emphasis on the policy implications of my thesis. From a practitioner's point of view, this research has several implications. Its findings can be used to improve the ways in which collaborative research between university and industry is governed, especially when collaborating through Ph.D. projects, and to increase the probability of success. By distinguishing a number of different success measurements, it can also help parties to develop more specific goals and adapt their governance accordingly. More precisely, the results allow partners to learn which specific aspects of governance have a significant effect on each different dimension of success. This is of particular importance, since on the one hand there has been an increasing tendency to get involved in university-industry collaboration (Thursby and Kemp, 2002), and on the other hand, collaboration is costly for partners (Thomson and Perry, 2006). This makes it even more important for partners to increase the probability of achieving substantial benefits from their collaboration.

2. Research collaboration and governance: A review of the literature

Abstract

This chapter aims to explore the existing literature on collaboration, define collaborative Ph.D. projects, and understand governance and success with respect to collaborations. If we consider (research) collaboration in a broader sense, and include collaborations outside the field of university-industry relationships, there is already a large body of research literature. This chapter reviews that literature to explain university and industry collaborations (Section 2.1), the different types of university-industry collaborations (Section 2.2) and collaborative Ph.D. projects (Section 2.3). A discussion follows on the governance of research collaborations (Section 2.4) and their success (Section 2.5). Finally, Section 2.6 presents conclusions.

2.1. Introduction

In the past decade, there has been increasing interest in inter-organizational relationships, especially as an external source of innovation (Perkmann and Walsh, 2007). Such outsourcing of knowledge creation has both an effect on an organization's financial performance through decreasing costs (Bettis *et al.*, 1992), as well as non-financial effects, such as an increased focus on organizations' core competencies (Dess *et al.*, 1995). The knowledge of inter-organizational relationships generally stands on the shoulders of two theories: the theory of interdependency and the theory of interaction (Geisler, 1995). The interdependency theory considers the impact of the external environment on inter-organizational relationships, and argues that a firm's survival is a function of its ability to adapt and fit in with the external environment. Accordingly, firms try to get involved in collaboration to manage resource interdependency and environmental uncertainty (Pfeffer and Nowak, 1976).

The interaction theory, in contrast, considers the process (internal development) of the relationships, and argues that inter-organizational ones are based on partners' prior relationships, mutual trust, commitment, and beliefs (Levinthal and Fichman, 1988). For the purpose of this study, both views are endorsed. There are different categories of inter-organizational relationships such as alliances, joint ventures, outsourcing initiatives (Vlaar *et al*., 2006), buyer-supplier relationships, franchising and licensing relationships (Dekker, 2004), innovation networks, and R&D consortia (Trott, 2005). While such relationships can involve a wide array of different partners, one particularly interesting type (from the perspective of source of external knowledge) is the collaboration between firms and universities. In a world with a high rate of technological change, innovation is considered a key factor of constant competition in firms. Consequently, firms need to improve their innovative capacity and collaboration is a way to foster their innovation potential (Faems *et al*., 2005). In the literature, several authors have pointed out that collaboration with universities, among other partners (e.g. competitors, suppliers, customers, government laboratories) increases firms' innovation ability (see for instance: Pavitt, 2003; Laursen and Salter, 2006). Universities are considered a knowledge source from which firms can receive the knowledge required, but with which firms can also exchange knowledge (Morandi, 2013; Perkmann *et al.*, 2013). The results of academic research on innovation are important especially for science-based industries such as biotechnology and semiconductors (Ponds *et al*., 2010). Through collaboration with universities, firms can improve their explorative capabilities, whereas collaboration with other types of partners, in contrast, contributes mainly to exploitation of the results (Rohrbeck and Arnold, 2006).

In recent decades, firms have not only tended to establish relationships with universities, but universities are also increasingly incentivized to develop closer relationships with firms. Because of the importance of university research for increasing local knowledge and consequently contributing to regional innovation processes, there is growing political pressure on universities to obtain more funds from industry and contribute to regional development as well (Geuna and Muscio, 2009). What is more, with basic funding decreasing, universities are actively diversifying their sources of income. Hence, involvement in collaboration provides a condition for both universities and industry to benefit from the synergies which result from exchanging complementary knowledge (Banal-Estañol *et al*., 2011).

There are several ways in which universities and industry can have a relationship, such as collaborative research, contract research, and patenting. In this thesis I focus on one interesting form of engagement, namely collaboration through a Ph.D. project, carried out by a doctoral candidate. Doctoral candidates are not only key producers of knowledge but potentially also important channels for transferring such knowledge to firms (Thune, 2009).

2.2. Different types of university-industry collaborations

Collaboration is a topic that has been addressed in various science disciplines including economics, business, sociology, political science, organizational behaviour, organization theory, and strategic management (Smith *et al*., 1995; Newman, 2001). In the supply chain management literature, for instance, Lambert (2008) found that relationships between firms lie on a continuum that ranges from arm’s length to vertical integration of the two firms. In a recent paper, Rezaei and Ortt (2012) suggest that each collaboration has attributes differentiating it from other relationships. Himmelman (1995) offers a typology for partnerships consisting of networking, coordinating, cooperating and collaboration, summarized in Table 2.1.

Table 2.1 Matrix of strategies for working together (Himmelman, 1995)

	Networking	**Coordinating**	**Cooperating**	**Collaborating**
Definition	Exchanging information for mutual benefit	Exchanging information for mutual benefit, and altering activities to achieve a common purpose	Exchanging information for mutual benefit, and altering activities and sharing resources to achieve a common purpose	Exchanging information for mutual benefit, and altering activities, sharing resources, and enhancing the capacity of another to achieve a common purpose
Relationship	Informal	Formal	Formal	Formal
Characteristics	Minimal time commitments, limited levels of trust, and no necessity to share turf; information exchange is the primary focus	Moderate time commitments, moderate levels of trust, and no necessity to share turf; making access to services or resources more user-friendly is the primary focus	Substantial time commitments, high levels of trust, and significant access to each other's turf; sharing of resources to achieve a common purpose is the primary focus	Extensive time commitments, very high levels of trust and extensive areas of common turf; enhancing each other's capacity to achieve a common purpose is the primary focus
Resources	No mutual sharing of resources necessary	No or minimal mutual sharing of resources necessary	Moderate to extensive mutual sharing of resources and some sharing of risks, rewards, and responsibilities	Full sharing of resources, and full sharing of risks, responsibilities, and rewards

Different types of partnership have different levels of interaction, integration, commitment and complexity (Thomson and Perry, 2006), and it is apparent that collaborations have a higher level of collective action than networking, coordination, or cooperation. To develop a better understanding of what collaboration really entails, let us first review several definitions before proposing our own definition of a collaborative Ph.D. project.

Table 2.2 Different collaboration definitions

Collaboration definition	**Author**
A process through which parties who see different aspects of a problem [or issue] can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible	(Gray, 1989)
A mutually beneficial and well-defined relationship entered into by two or more organizations to achieve common goals. The relationship includes: a commitment to: mutual relationships and goals; a jointly developed structure and shared responsibility; mutual authority and accountability for success; and sharing of resources and rewards	(Mattessich and Monsey, 1992)
Any joint activity, by two or more organizations, intended to create public value by working together rather than separately	(Bardach, 1998)
An interactive process among individuals and organizations with diverse expertise and resources, joining together to devise and execute plans for common goals as well as to generate solutions for complex problems	(Gronski and Pigg, 2000)
A process in which autonomous actors interact through formal and informal negotiation, jointly creating rules and structures governing their relationship and ways to act or decide on the issues that brought them together; it is a process involving shared norms and mutually beneficial interactions	(Thomson, 2001; Thomson and Perry, 2006).

Table 2.2 shows a number of definitions as found in the literature. Obviously, in all of the above definitions, collaboration is a process that includes activities between two (or more) actors in order to achieve goals. The actors can be individuals or

organizations and the collaboration can be built between individuals, between organizations, or between organizations and individuals.

In university-industry collaboration, two main actors engage in collaboration to fulfil their goals. Relations between industry and university can be in various forms, constituting a continuum from collaborative research projects (based on contracts between university and industry), intellectual property rights (IPR) and spin-offs, labour and student mobility and consultancy, to "soft" forms such as attending conferences and creating electronic networks (Geuna and Muscio, 2009). There is a similar classification which categorizes knowledge transfer in two categories: formal and informal channels (Grimpe and Hussinger, 2013). Formal channels refer to the way knowledge is transferred based on contracts, which lead to outputs such as patent, license and publication. For instance licensing contracts (Thursby *et al*., 2001; Thursby and Kemp, 2002) and joint research projects (Cockburn and Henderson, 1998) are considered to be in this category. In contrast, informal channels are mechanisms which focus on the non-contractual interactions between university researchers and industry personnel through conferences or meetings (Grimpe and Hussinger, 2013). Drawing on a survey, Schartinger *et al*. (2001) identified four types of interaction that are most frequent between universities and firms: supervision/financing of Ph.D. and Master theses, contract research, joint research and employment of university researchers by firms. Generally speaking, in informal research collaboration, the university has a short-term role as partner of a firm (Hall *et al*., 1998). We can summarize different types of interaction between university and firms in five categories offered by D'Este and Patel (2007), see Table 2.3.

Table 2.3 Types of interaction divided into five categories (D'Este and Patel, 2007)

Interaction Types	**Explanation**
Meetings and conferences	Attendance at industry sponsored meetings Attendance at conferences with industry and university participation
Consultancy and contract research	Consultancy work (commissioned by industry, non-involving original research) Contract research agreements (commissioned by industry and undertaken only by university researchers)
Creation of physical facilities	Setting up spin-off companies Creation of physical facilities with industry funding (including campus laboratories, incubators and cooperative research centres)
Training	Postgraduate training in a company (e.g. joint supervision of Ph.D. students) Training company employees (through course enrolment or personnel exchanges)
Joint research	Joint research agreements (involving research undertaken by both parties)

By reviewing the literature, Perkmann *et al.*, 2013 categorized collaborations between university and industry in two groups: academic engagement and commercialization.

The commercialization of academic knowledge comprises the patenting, licensing of inventions, and academic entrepreneurship. These phenomena dominate the literature on university and industry relations, as observed by (Perkmann *et al.*, 2013). The same authors also introduce another category of channels between university and industry, coined "academic engagement". This is defined as "knowledge related collaboration by academic researchers with non-academic organizations" (Perkmann *et al.*, 2013, p. 424). It includes different forms of interaction ranging from formal activities (collaborative research, contract research, and consulting) to informal activities such as meetings and participation in conferences, (D'Este and Patel, 2007; Grimpe and Hussinger, 2013). According to this line of literature, firms consider academic engagement not only more valuable as a channel of knowledge transfer compared to licensing university patents (Cohen *et al.*, 2002), but universities also benefit more from academic engagement in a financial sense, compared to the income from intellectual property (Perkmann *et al.*, 2013). As noted by Perkmann and colleagues, while studies on commercialization dominating the literature, studies on academic engagement are still scarce. The present study is one contribution to our understanding of academic engagement in order to improve this current intellectual imbalance. Figure 2.1 summarizes our discussion to illustrate the position of this study in the field.

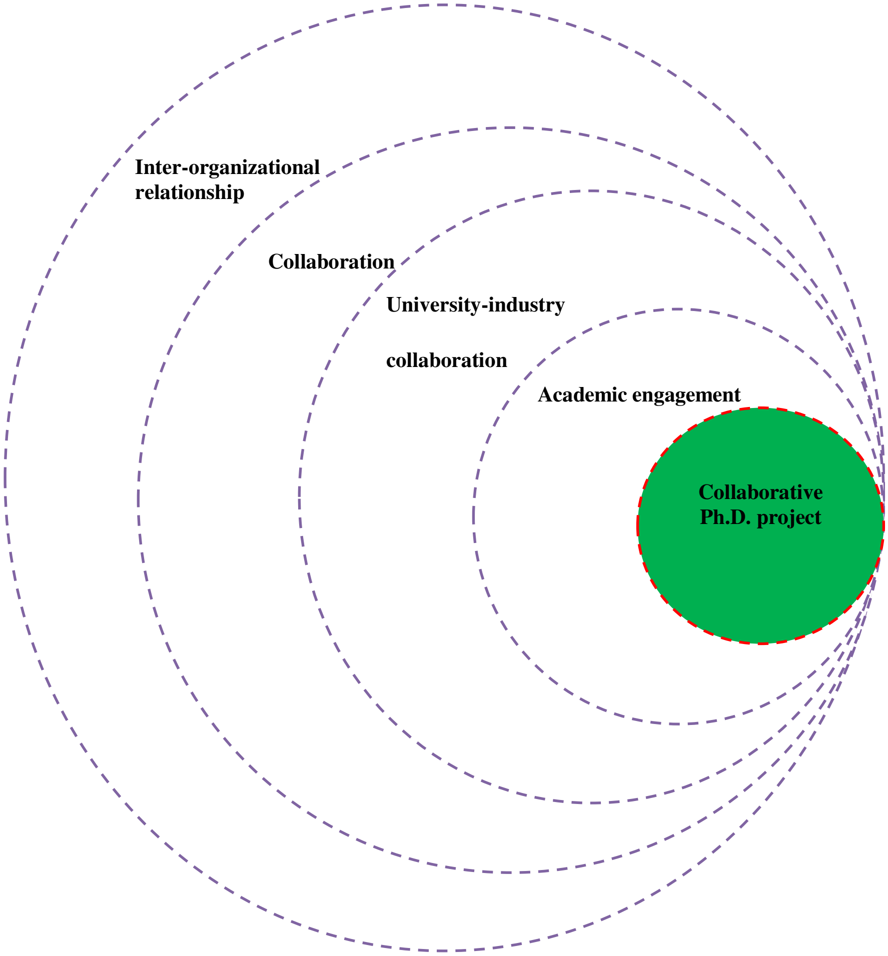

Figure 2.1 The positioning of this thesis in a broader domain

2.3. Collaborative Ph.D. projects

Collaborative Ph.D. projects are best characterized as being between three partners: a firm, a university, and a doctoral candidate. The candidate is enrolled full or part-time in a program that leads to a doctoral degree. Thune (2009, 2010) believes that a doctoral candidate can have each of the following three roles: creation of knowledge; transfer of knowledge, and formation and maintenance of network ties between university and firms. This latter role relates to the social ties that exist between Ph.D. candidates and their supervisor which can also lead to new links after graduation (Thune, 2009, 2010). In a collaborative Ph.D. project, the research is a planned and structured activity carried out by the Ph.D. candidate.

Considering the aforementioned explanation, we define a *collaborative Ph.D. project as a project with a typical duration of 3-4 years which involves a firm, a Ph.D. candidate, and a university, which all work together to meet their (common or individual) goals.*

In existing literature, only a few studies deal with doctoral candidates. For instance, Wallgren and Dahlgren (2005) conducted a survey at the Swedish Graduate School for Applied IT and Software Engineering. They found that not only the individual characteristics of doctoral candidate affect the doctoral candidate's role and participation in knowledge development, but also the type of firm involved (e.g. R&D intensive, engineering or consultancy) is a determining factor. Salminen-Karlsson and Wallgren (2008) focused on the role of university supervisors and firm supervisors of graduate candidates in a specific context of industrial research schools, within the special framework of Swedish higher education. They mainly found that cooperation between university supervisors and industry supervisors requires the ongoing cooperation between them even in other areas (i.e. personal relation) and frequent meetings. Moreover, the experience and motivation of former

Ph.D. candidates to enter into entrepreneurship are studied by Hooley et al. (2011). The results of 40 interviews, conducted with doctoral graduates from the UK who had undertaken entrepreneurial ventures, showed that personal characteristics (i.e. enthusiasm, optimism, passion, and energy) and access to the financial, social and educational capital are important elements in successful venture creation. Finally, Mangematin, (2000) and Manathunga et al. (2009) investigated the job market for Ph.D. graduates. By conducting a survey of 400 engineering science Ph.D. candidates from the University of Grenoble, they concluded that the proper designed incentives between Ph.D. candidate and supervisor increase the scientific production and vertical collaboration.

The specific topic of the present thesis, however, has not yet been addressed. How a university and its partner govern their collaboration and how governance affects project performance have not yet been the subject of research. As mentioned by Perkmann *et al*. (2013), identifying the consequences and outcomes of collaboration allows policy-makers to understand which organizational forms lead to each collaboration outcome. They conclude that it is necessary to focus on how collaborations between universities and industrial partners are maintained and that more studies are required to investigate the benefits of academic engagement.

2.4. Governance of collaborative Ph.D. projects

Collaborations between universities and industry have several types of potential benefits for both partners. However, the considerable benefits are not always achieved in practice. Some reasons can be related to ignoring the motivations of the exchange, selecting inappropriate partners for collaboration, unsuitable governance structure, and underestimating the importance of close communication (Morandi, 2013). Thomson and Perry (2006) identified five dimensions of collaboration: governing and administering (structural dimensions); mutuality and norms (dimensions of social capital); and organizational autonomy (an agency dimension). Stoker (2004, pp. 17-28) argues that governance *"refers to the rules and forms that guide collective decision-making. That the focus is on decision-making in the collective implies that governance is not about one individual making a decision but rather about groups of individuals or organizations or systems of organizations making decisions".* According to the governing dimension, collaboration partners follow the structure created by partners to solve problems during the project, and make decisions about its content (Thomson and Perry, 2006).

McCaffrey *et al*. (1995) argue that participative management, whereby all partners are involved in the decision-making process, is one explanation of successful collaboration (even though the precise level of each party's involvement may differ, depending on the situation). By applying participative decision-making, partners can offer proper solutions to problems and solve them jointly while respecting the other partner's opinion (McCaffrey *et al*., 1995). Similarly, Ansell and Gash (2008), offer a new strategy of governing called "collaborative governance", in which partners are directly involved in a decision-making process that is formal, consensus-oriented (even if agreement might not be reached in every case) and deliberative in order to manage programs. Collaborative governance is a structured arrangement (Padilla and Daigle, 1998), characterized by joint activities, joint structures and shared resources (Walter and Petr, 2000). In contrast, centralized governance puts only one partner in charge of decision-making and management, thus marking another mode of governance.

Geuna and Muscio (2009) emphasize the importance of governance of the university-industry interaction and knowledge transfer process by looking at the existing literature on research collaborations, intellectual property rights, and spin-offs. They argue that in collaborative research, the characteristics of the firm, the university and the individual researcher all play a crucial role in collaboration governance. Morandi (2013) studied the governance of R&D collaboration. Using case studies, he focused on how R&D collaboration activities are coordinated and controlled by participants. He found that project and relationship characteristics impact on the management of collaboration. For instance, task uncertainty leads to the decentralization of coordination and control practices, equivocality provides incentives for both partners to engage in coordination, and reciprocal interdependence among partners requires the exploitation of up-to-date project plans. In a survey among UK scientific researchers, D'Este and Patel (2007) found that individual researchers' characteristics have a stronger impact on communication with the firm than the characteristics of the departments or university involved. Researchers with previous collaboration experience and a high academic rank increase the probability of frequency of interaction between university and firm. Other characteristics identified as having a major impact on governance include the university's academic reputation that can increase the probability of signing licensing agreements (Elfenbein, 2007). Moreover, maintaining close relationships and good communication between partners facilitates building trust, mutual respect, shared understanding and commitment (Mattessich and Monsey, 1992; Lasker *et al*., 2001; Lambert, 2008).

Studying the governance of university-industry collaborations is important because the way partners govern their collaboration also impacts on its success. By evaluating six collaborative research projects, Barnes *et al.* (2002) identified factors that had an impact on the collaboration success, including the choice of partner, environmental aspects, and project management. More precisely, they found that the factors determining success were: the partner's evaluation, good process monitoring, a structured, objective setting, effective communication between partners, trust and commitment and a flexible management structure to cope with changes. Jeffrey and Butcher (2007) investigated the connection between supervision, project management, and communication factors and the perceived collaborative research success from the Ph.D. candidate's perspective. They found that previous collaboration among partners, the level of supervisors' enthusiasm for the project, a lack of problems with project timescales and high frequency of meetings between partners impacted on the success of collaboration.

By focusing particularly on the governance of collaborative Ph.D. projects, I aim to further open the black box of university-industry collaborations and thus understand what elements form the core of collaboration governance, how actors decide on the content of projects and manage their relationships in order to make the collaboration successful.

2.5. Success factors of collaborative Ph.D. projects

One important element of this thesis is determining the success of collaboration. Since university-industry projects generally combine the university's objective to publish as well as the firm's objective to commercialize, both publication (Gulbrandsen and Smeby, 2005) and patenting (Perkmann *et al*., 2013) can be considered the consequences of academic engagement. Patenting researchers appear to have more publications than their non-patenting colleagues (Agrawal and Henderson, 2002). However, the involvement in commercialization activities may negatively impact the pace of publication: researchers who commercialize their work tend to keep their research results longer to themselves compared to other researchers (Perkmann *et al*., 2013). In this respect, an analysis of the output of collaborative Ph.D. projects is still lacking.

In the literature, the success of university-industry collaboration is mostly considered a one-dimensional concept, measured for instance by technology or knowledge development (Barnes *et al.,* 2002), the knowledge transferring ability between partners, or the development and commercialization of a new product. Butcher and

Jeffrey (2007) also investigated the perceived success of collaborative research from the Ph.D. candidate's perspective, without considering the various dimensions of success. Other researchers considered different dimensions for collaboration success without using them in their analysis, see Santoro, 2000 and van Gils, 2012.

Using a single dimension to measure success, or considering several dimensions without analysing them, provides only a limited view of the complexities of a Ph.D. project. In this thesis I propose several dimensions for measuring the success of a collaborative Ph.D. project.

2.6. Conclusion

This chapter aims to provide a general overview of the existing literature on collaboration, define collaborative Ph.D. projects, and understand governance and success of collaboration. By reviewing the existing literature of collaboration, it clarifies the importance of governance and its impact on the success of collaboration. Moreover, the literature review shows that among different types of university-industry collaboration, collaborative Ph.D. projects have been neglected. All these gaps motivate an in-depth study of governance and success in the context of collaborative Ph.D. projects. My aims are to find how universities and industry govern collaborative Ph.D. projects, how these governance choices impact successful outcomes, and how the output performance of doctoral candidates in collaborative projects differs from their non-collaborative peers. These three questions are already formulated in Chapter 1. The questions are investigated in chapters 3-5 by using data collated from empirical studies.

3. Governance mode choice in collaborative Ph.D. projects[1]

Abstract

Joint Ph.D. projects are a prominent form of research collaboration, connecting universities to firms and public research organizations. When entering into such collaborations, partners need to make choices regarding a project's governance. This paper investigates how a university and its partners govern such projects, including decision-making, daily management and disclosure policies. Earlier studies show that shared governance modes have had a higher success rate than centralized governance modes. Nevertheless, more than two thirds of the 191 joint Ph.D. projects we investigated opted for centralized rather than shared governance. Our findings show that: (i) geographical and/or cognitive distance render the adoption of a shared governance mode less likely; (ii) the partner controlling critical resources tends to centralize governance, and (iii) partnering firms are more likely to put restrictions on publication output than public research organizations. We therefore recommend that universities and their partners take these aspects into account when selecting such projects.

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[1] This chapter is based on:
Salimi, N., Bekkers, R., Frenken, K. (2014). Governance Mode choice in Collaborative Ph.D. projects. *The Journal of Technology Transfer,* DOI: 10.1007/s10961-014-9368-5.
Earlier versions of this paper were presented at a research seminar held at Eindhoven University of Technology's department of Industrial Engineering and Innovation Sciences and at a colloquium at Delft University of Technology.

***Keywords*:** university-industry collaboration, collaborative Ph.D. project, shared governance, centralized governance, proximity, resource imbalances, publication disclosure

3.1. Introduction

Knowledge production can be seen as a process in which scarce resources are exploited to produce a specific output. From this economic viewpoint, the question of knowledge production can be outlined as a traditional 'make-or-buy' decision (Williamson, 1973); a firm can purchase knowledge through market transactions (e.g. consultancy, license agreements) or develop knowledge in-house through R&D investment. If transaction costs are relatively low, a firm will opt for market transaction, while if transaction costs are relatively high, a firm will favour in-house production.

Inter-organizational collaboration provides an alternative to make-or-buy. Although collaborative arrangements in knowledge production have always existed in certain sectors, dating back to the Industrial Revolution (Nuvolari, 2004), R&D collaboration has become especially salient in high-technology industries from the 1980s onwards (Hagedoorn *et al*., 2000; Powell *et al*., 2005). The popularity of collaboration can be appreciated by bearing in mind the disadvantages of both in-house production and market purchase. With the growing complexity and pace of innovation, it is becoming increasingly harder for firms to master all the relevant knowledge domains (Granstrand *et al*., 1997). Hence, to rely solely on in-house knowledge production is too costly and risky under most conditions. At the same time, markets for knowledge are far from perfect, mainly because knowledge is an experience good: its economic value can only be evaluated *ex post*. The growing complexity and pace of innovation render such markets even more imperfect. As a result, firms often engage in inter-organizational research collaborations to pool resources, to exploit complementary assets, and to share the risks inherent in R&D (Teece, 1986).

Inter-organizational collaboration in knowledge production is a "mixed bag". Actors may have different motives ranging from technology sensing and basic R&D, joint product development and value chain optimization, to standard-setting and co-patenting. Moreover, forms of governance range from informal networking to R&D partnerships and equity joint ventures. Hence, the core research challenge so far has been to identify the choice of knowledge production mode for different motives and under varying environmental conditions (Teece, 1986).

Here, we focus on collaborations involving universities. In present day science-based innovation processes, universities have been central in the R&D process. There is clearly a rising trend in the number of collaborations between universities on the one hand and firms or public research organizations (PROs) on the other, as indicated by co-publications (Ponds *et al*., 2007). Firms and PROs have several reasons to collaborate with universities (Liebeskind *et al*., 1996; Ponds *et al*., 2007), namely: (i) in many knowledge domains, cutting-edge knowledge can only be gained by actively working together with universities as such knowledge is not yet codified, (ii) universities often have unique resources including databases and research facilities that would be too expensive for firms or PROs to construct in-house, (iii) through collaboration, university knowledge can immediately be made relevant to the specific problem-context of the firm or PRO.

Doctoral candidates are key producers of new knowledge and are also considered the main channels for transferring knowledge to firms (Thune, 2009). The relationship structure between the three main partners in this collaboration (Ph.D. candidate, university and its partner) makes the collaboration governance very complex. The specificity of joint Ph.D. projects not only stems from the nature of the partnership, but also from its duration (three years or longer) and type of knowledge (scientific research). Despite this specificity, joint Ph.D. projects are far from homogeneous regarding the micro-level structure of governance, as the exact mode of governance varies considerably. In particular, we can distinguish between a "shared" governance structure where project management is a shared responsibility and decisions are made by mutual agreement, and a "centralized" governance structure where the responsibility for project management and authority in decision-making are allocated to one of the two parties.

Generally speaking, collaboration in scientific research is organized using shared governance structures (Gibbons *et al*., 1994). In most instances, distributing authority among team members involved in scientific research promotes flexibility, creativity and efficiency (Liebeskind *et al*., 1996, Shrum *et al*., 2007). In the specific case of joint Ph.D. projects between a university partner and an external partner, one study found that projects with a shared governance structure did indeed have more outputs than those with centralized governance, where the governance was dominated by one of the partners (Salimi *et al*., 2013, Chapter 4). Hence, the question arises under what conditions parties opt for a shared or centralized governance structure.

Joint Ph.D. projects are, by nature, organizationally complex, involving at least two partner organizations and the Ph.D. candidate in question. What is more, the return on a project's investments is fundamentally uncertain. Consequently, contingencies are hard to foresee, let alone codifiable in legal contracts specifying the exact roles and responsibilities of all parties involved. This is why contracts are only of limited value in joint Ph.D. projects and partner organizations rely primarily on mutual trust and on-going cooperation. If mutual trust is established before the start of the project, or if such trust can easily be established during the project, two partners are more likely to accept a shared governance structure. By contrast, if this trust is not already established nor easily created, the partners are more likely to settle for a centralized governance structure, for example, on the basis of who funded the project.

Below, we apply a proximity framework to probe the conditions that facilitate a shared governance mode in research collaboration

(Rallet and Torre, 1999; Boschma, 2005). In most studies, the proximity framework is adopted to predict collaboration intensity: the more proximate two actors are, the more likely they collaborate in joint research projects (Autant-Bernard *et al.*, 2007; Ponds *et al.*, 2007, Balland; 2012). Here, we are not interested in the collaboration frequency between organizations, but in the mode of governance they apply under varying conditions.

3.2. Theoretical background

3.2.1. Proximity, resources and governing mode

It has become common to distinguish five forms of proximity: geographical, social, institutional, cognitive, and organizational (Boschma, 2005). Each form of proximity refers to a particular characterization of the relationship between two actors, where proximity refers to some kind of similarity, and its reverse, being distance[1], refers to some kind of dissimilarity. Our main hypothesis holds that organizations which are distant will find it more difficult to create conditions of trust and are thus less likely to opt for a shared mode of governance. Though shared governance provides a better basis for mutual collaboration among equal partners (Shrum *et al.,* 2007), it is also likely to introduce ambiguities and potential conflicts regarding decision-making authority (who decides in which case?), principles (what is the project's main objective and underlying value?) and routines (how did we make decisions in the past in similar contexts?) (Torre and Rallet 2005). If partners are already proximate while entering a partnership, be it geographically, cognitively or socially, trust is easier to establish, and a shared governance is more likely to be effective. Hence, proximate partners are expected to prefer a shared governance mode over a governance mode that is centralized at one partner.

[1] Note that our theoretical framework reasons from 'proximity', whereas our hypothesis and relevant variables are consistently defined in terms of 'distance', being the opposite of proximity.

Instead, distant partners will more likely organize governance either at the university or at the university's partner organization given that the conditions to create a common basis of mutual trust and understanding are less favorable. Whether they centralize governance at the university or at their partner, will in turn depend on both partners' relative strategic interest in the project.

Geographical distance refers to distance in physical space. The benefits from geographical proximity in joint innovation projects have been highlighted mainly with reference to the need for face-to-face interactions (Boschma, 2005). Indeed, tacit knowledge is easier transferred through face-to-face interaction, which in turn is easier to organize when partners are located in close vicinity. Furthermore, the more distant two partners are located from each other, the more time and resources are required for meetings, the less frequently meetings can take place, and the more difficult it will be to create mutual trust (Cummings and Kiesler, 2005, Ponds *et al.,* 2007, Bouba-Olga *et al.,* 2012). In such instances, centralizing governance at one location rather than distributing it over two locations is more practical, as governance requires face-to-face interaction. By contrast, partners co-located in close vicinity may opt to share governance over its two locations. Hence, our hypothesis holds:

Hypothesis 1a: As the geographical distance between partners increases, a shared governance mode becomes less likely

Social distance refers to what extent actors are unacquainted with each other. This can range from being close friends to being complete strangers. In previous analyses of research collaboration, social proximity has been referred to as the extent to which two actors have collaborated in the past on previous projects (Bouba-Olga *et al.,* 2012). The continuation of a relationship can be seen as an indication of success (Salimi *et al.,* 2013, Chapter 4), which creates trust among partners. Hence, the common experience will greatly facilitate the organization and management of a following project, making it more likely that roles and responsibilities are shared. Conversely, first time collaborations are characterised by social distance. Hence, the sharing of responsibilities will be more difficult to achieve and governance is more likely to be centralized. According to this reasoning:

Hypothesis 1b: As the social distance between partners increases, a shared governance mode becomes less likely

A third type of distance concerns **cognitive distance**, which refers to the extent to which partners have a different knowledge base (Nooteboom, 2000). This form of distance is possibly the most challenging in research collaboration, because a lack of common knowledge hampers effective communication and interpretation. In cases where collaborators lack a common understanding, it will be difficult to establish trust because one partner's claims are hard to validate by the other, and *vice versa*. Consequently, a shared mode of governance is less likely. Instead, one would expect governance to be centralized at the partner who is most familiar with and knowledgeable about the subject matter. Hence:

Hypothesis 1c: As the cognitive distance between partners increases, a shared governance mode becomes less likely

Another form of distance in research collaboration concerns institutional distance. Actors are said to be institutionally distant when they operate under a different set of norms, values and incentives (Ponds *et al.,* 2007). For example, a university-industry collaboration is characterised by institutional distance, as firms have different incentives (to apply knowledge and to make profit) than a university (to seek novelty and to publish results). By contrast, an inter-university collaboration or an inter-firm collaboration can be characterised by institutional proximity, since actors in such collaborations have very similar incentives. Given that our study only deals with collaborations between a university and external partners, all relations are by definition institutionally distant. However, our data include both collaborations between a university and a firm, as well as those between a university and a PRO. Thus we have added as a variable a dummy "industry" to distinguish university-industry relations from university-PRO relations.

Finally, **organizational distance** is a fifth type of distance and generally refers to the extent to which collaborators operate autonomously. Conversely, organizational proximity refers to the extent that collaborators are governed under a hierarchical relationship (e.g., two subsidiaries of a single firm). In our study, we deal with collaboration between two different organizations. Hence, the relationship is by definition characterized by organizational distance, which is why no hypothesis will be developed regarding the organizational dimension.

A second factor that affects the governance mode is resource imbalance. In particular, once one of the partners holds resources that are critical, such as data and research facilities, this partner will probably be reluctant to share project management and decision-making. In such contexts of resource imbalance, a shared governance mode is less likely for at least two reasons: strategic and pragmatic. Strategically, the holder of critical resources is interested in temporarily sharing resources for their joint exploitation, and not in transferring these resources on a permanent basis. By temporarily granting access to critical research resources such as data or facilities to external partners, an organization runs the risk of losing its competitive advantage in the longer term. Hence, the granting partner will be more prone to stay in control of the exact course and content of the research project. And, pragmatically, there are reasons to centralize governance at the partner holding the critical resources. The use of critical resources in research projects requires the possession of complementary tacit knowledge. As this knowledge is primarily centralized with researchers employed by the partner granting access to the resources, management and decision-making will mostly be allocated to those with the most knowledge about the productive use of the resources. Hence:

Hypothesis 2: If one of the partners holds critical resources, it is *more likely to control the governance*

A typical feature of research projects is that resources are not only being used, but also being created. Resources such as data, software and research facilities are not only potential inputs, but also potential outputs. Furthermore, a Ph.D. project essentially involves the training of the Ph.D. candidate, that is, the creation of human capital. Actually training of the Ph.D. doctorate which is the highest degree in academia is considered as an investment in human capital (Mangematin, 2000). Not only investing in the Ph.D. degree is important for the candidates because of the positive relationship between having Ph.D. degree and rate of employment and salaries, but also the characteristics of human capital in terms of their level of education, knowledge and skills are critical for firms (Hitt *et al.,* 2001). Although partners, almost by definition, only enter into collaboration if both have something to gain, the distribution of the resulting output may be imbalanced. For example, some projects are initiated by the university because it foresees interesting research opportunities, while other projects are initiated by a university's partner, for example when a key employee wishes to obtain a Ph.D. degree. Though motivations can be many, if one of the two partners is the sole project funder, this can be seen as "revealed" evidence that the main interest in the project lies with that partner. Hence:

Hypothesis 3: If one of the partners is the sole project funder, it is more likely to control the governance

3.2.2. Proximity, resources and disclosure

What probably causes the most specific tension in university-industry projects are the divergent incentives between universities and their partners regarding the disclosure of research output (Partha and David, 1994; Etzkowitz and Leydesdorff, 2000). University researchers, almost without exception, are evaluated by the research output they generate (mainly in the form of scientific papers) and its impact in the scientific community (mainly in the form of citations). This means that they will be eager to publish the research output of a joint Ph.D. project as widely as possible. Furthermore, they have an incentive to publish their results quickly as competing research teams may pre-empt them, lowering their (citation) impact. While university patenting (often combined with publication restrictions) is becoming increasingly important, it is still a relatively rare phenomenon in most countries.

Firms, by contrast, develop knowledge with a commercial application in mind. Given the competition from fellow firms, the public disclosure of research output would render this knowledge accessible to competing firms. Hence, firms have an interest not to disclose research output, or at least put restrictions on what is exactly being disclosed and when.

Importantly, there are situations where tensions regarding publication may be negligible. For example, some firms are interested in co-producing scientific research as a means of building 'absorptive capacity', that is, the capacity to understand and make use of knowledge produced elsewhere (Cohen and Levinthal, 1990; Rosenberg, 1990). Firm employees who engage in scientific research activities are also better able to exploit the cutting-edge scientific knowledge produced elsewhere and published in the public domain. Once the results are published, other firms only have access to the codified part of the knowledge produced, while the absorptive capacity remains proprietary.

Restrictions on the publication of results stemming from a joint Ph.D. project can be considered a special mode of governance. Obviously, restrictions will be more likely if the university collaborates with a firm rather than with a PRO. The latter usually has a similar interest in disclosing results as quickly and widely as possible, given their public mission. That is, PROs are more proximate to universities than firms, because their incentive structure resembles the university structure more than that of firms. Therefore we can put forward the following hypothesis:

Hypothesis 4: Industry involvement renders publication restriction more likely

Resources, again, are also expected to play a role in publication restrictions. The particular imbalance in critical resources can affect the dominant institutional logic. If the university holds the critical resources, it can be expected to grant a university partner access to these resources provided that results can be published without restrictions. This outcome is likely because the university has a stronger negotiating position than the firm. Conversely, if the university's partner holds the critical resource, the partner can be expected to put restrictions on publications, as a means to protect their resource from competitors. Such an outcome is likely because, in this context, the university's partner has a stronger negotiating position than the university. Thus the following hypotheses can be derived:

Hypothesis 5a: If the university holds critical resources, publication restriction is less likely

Hypothesis 5b: If the university's partner holds critical resources, publication restriction is more likely

Similarly, negotiating positions will differ according to the funding source. If one of the actors is the sole funder of the project, it is likely that the institutional logic of the funding organization applies. This means that if the university finances the entire project from its own funds, it will be unlikely to accept any restrictions on publication, while if the university's partner funds the entire project, it is more likely that publication restrictions will apply. Hence:

Hypothesis 6a: If the university is the sole project funder, publication restriction is less likely

Hypothesis 6b: If the university's partner is the sole project funder, publication restriction is more likely

3.2.3. Overview of hypotheses

Based on our theoretical outline, we have developed a total of ten hypotheses. We have put forward five hypotheses regarding the choice of a shared or centralized mode of governance and five hypotheses on the option of putting restrictions on the disclosure of results in the form of publications. Table 3.1 provides an overview of the hypotheses in our study.

Table 3.1 Overview of hypotheses

Hypotheses regarding modes of governance
Hypothesis 1a: As the geographical distance between partners increases, a shared governance mode becomes *less* likely
Hypothesis 1b: As the social distance between partners increases, a shared governance mode becomes *less* likely
Hypothesis 1c: As the cognitive distance between partners increases, a shared governance mode becomes *less* likely
Hypothesis 2: If one of the partners holds critical resources, it is *more* likely to control the governance
Hypothesis 3: If one of the partners is the sole project funder, it is *more* likely to control the governance
Hypotheses regarding publication restriction
Hypothesis 4: Industry involvement renders publication restriction *more* likely
Hypothesis 5a: If the university holds critical resources, publication restriction is *less* likely
Hypothesis 5b: If the university's partner holds critical resources, publication restriction is *more* likely
Hypothesis 6a: If the university is the sole project funder, publication restriction is *less* likely
Hypothesis 6b: If the university's partner is the sole project funder, publication restriction is *more* likely

3.3. Methodology and data

3.3.1. Data collection

Our empirical analysis is based on data from collaborative Ph.D. projects at the Eindhoven University of Technology that resulted in published doctoral theses. We analyzed all such theses published between the years 2000-2011 in all departments of the university.[1] Data was gathered by asking the Ph.D. candidates[2] who conducted these collaborative Ph.D. projects to fill in a questionnaire. We included the university's collaborations with both firms and PROs, which are to some extent similar in The Netherlands in that both rely heavily on external sources to fund research and both value technology development at least as important as knowledge creation.[3] We excluded collaborations with other universities and (other) governmental bodies, as we believe that such collaboration are rather different in nature. We also excluded collaborations with three or more partners.

Whether a particular Ph.D. thesis resulted from collaboration, was determined by reading the abstract, acknowledgements and other relevant front matter of these documents. Of the total of 1783

[1] Departments concern Applied Physics, Chemical Engineering, Electrical Engineering, Mathematics and Computer Sciences, Mechanical Engineering, Built Environment, Biomedical Engineering, Industrial Design, Industrial Engineering and Innovation Sciences. The latter four departments, the departments with a low number of respondents, are grouped into a single category in the regression analysis to avoid dummy values to be affected too much by outliers. We label the single category Management/Design (although we understand that this label does not cover the Biomedical Engineering department well).

[2] In terms of context, it might be good to explain here that in The Netherlands, Ph.D. candidates typically have an employment contract with the university and receive a regular salary. In that sense, involving them in a collaboration with a firm should probably not be seen a form of exploitation of these individuals.

[3] Here, it is important to stress that in The Netherlands, most of these institutes rely heavily on contract research and other sources of commercial funding, and have very limited public funding, making them quite comparable to firms in many respects. We do realize this situation is notably different in most other countries.

Ph.D. theses in the specified period, we identified 496 (28%) that had resulted from a collaboration with either a firm or a PRO. (From here on, both groups will be referred to as 'university's partner' or 'partner'). Through various methods, we were able to find up-to-date contact details of the former Ph.D. candidates for 408 of these 496 collaborations. Each individual was approached with the request to submit a questionnaire, in other words we did not draw a sample but contacted the full population. After sending two subsequent reminders, we received 191 completed questionnaires, which is a response rate of 47%. To check for possible non-response bias, we used the projected respondent method offered by Armstrong and Overton (1977). This method assumes that non-respondents are more similar to late respondents. After analyzing the differences between several waves of respondents, we found no serious concerns regarding non-response bias.

The received responses are almost evenly split between collaborations with firms (53%) and those with PROs (47%). Given the presence of a number of large technology companies in the Eindhoven region, it will come as no surprise that firms such as Philips and ASML are well represented in the responses, but there are also numerous partners with only one or two collaborations. Of all the respondents, 130 (66%) had the Dutch nationality, emphasizing the fairly international character of these candidates.

A consequence of our hypotheses is that we require data from all three partners' perspectives (university, Ph.D. candidate, and collaborating partner). In an ideal world, such data would be collected from all three sources. However, this approach would also have very serious drawbacks. First, it is often difficult to identify and find up-to-date contact information for all the relevant persons. Second, requiring all three completed questionnaires for each case we receive would have a dramatic effect on the total number of usable cases.[1] Third, the supervisors at the university or partner institute may not very accurately remember the details of a specific collaboration, especially if they were involved in many Ph.D. projects and collaborations over a long period. In contrast, for the Ph.D. candidates, it was a once in a lifetime experience, which they are likely to remember in detail, resulting in higher data quality. Considering all the above, we decided to collect data by sending questionnaires only to Ph.D. candidates.[2]

We are aware, though, that using a single source may result in common method bias. To address this concern, we applied some remedies offered by Podsakoff *et al.* (2003). Among other things, we focused our questions as much as possible on actual facts, which were open to interpretation or opinion (e.g. who funded the research, or whether there was a publication restriction or not). We also piloted a concept survey with several members of the population, to ensure all questions were clear and understood the way we intended them, and to ensure that we offered the appropriate answering categories. On the basis of this pilot, we made a number of changes and added examples where helpful. Finally, in addition to remedies for preventing common method bias, to make sure there would be no common method bias after conducting the survey, we used Harman's one-factor test. In this method, all variables (dependent and independent) are entered into

[1] If we assume the response rate for all groups is identical to what we had for Ph.D. candidates (47%), and that non-response is independent between respondents, then the response rate for complete cases would be $0.47 \times 0.47 \times 0.47 = 0.104$ only, which would have left us with only 42 cases. Moreover, it is likely that the identification and response rate among supervisors at both university and partner are lower than those for Ph.D. candidates, which would result in even fewer cases.

[2] It also implied that we could not ask the university supervisor and the university's partner directly about the levels of trust, which – as we assume – affects the governance mode choice. Neither can one expect the respondent (the Ph.D. candidate) to be able to judge how trustful the relationship was between the collaborating partners. Instead, as explained in the theory section we derive hypotheses based on the underlying theoretical arguments in the proximity literature.

an exploratory factor analysis (Podsakoff *et al.,* 2003). Based on the result of the factor analysis, nine factors were extracted, accounting for 73 percent of the total variance, with the first factor accounting for about 11 percent of the total variance. This suggests that our study does not suffer from common method bias.

3.3.2. Description of variables

According to our hypotheses, the dependent variables in our study concern the governance mode of the collaboration and potential publication restrictions. While the hypotheses only distinguish between 'centralized' and 'shared' governance modes, we actually collected more detailed data on the way these projects were governed, recognizing there might be different dimensions at play. As can be seen from Table 3.2, we measured both the management (such as daily supervision) as well as the decision-making aspects (relating more to one-time, fundamental and critical issues, such as the topic, the aims and objectives, and so on). In each case, we determined whether the prominent partner is the university (a centralized mode), the partner (also a centralized mode), or both (a shared governance mode). Concerning our measurement of publication restrictions, we only considered the situation where the partner imposed such restrictions.

Table 3.2 Descriptive statistics of dependent variables

Dependent variable	**Value**	**N**
Prominent partner in managing the coordination	The university: n=88 (46%) The partner: n=38 (20%) Both partners: n=65 (34%)	191
Prominent partner in decision-making	By the university: n=93 (49%) By the partner: n=37 (19%) Both partners: n=61 (32%)	191
Publishing some results was restricted by university's partner	Yes: n=19 (10%)	191

Table 3.3 reports the correlation between dependent variables. Not surprisingly, we thereby observed some degree of correlation between the management and the decision-making dimensions. Yet, they are certainly not perfectly correlated, which motivated us to test our hypotheses for both different dimensions. There appears to be no significant correlation between the governance modes and the publication restriction.

Table 3.3 Correlation between dependent variables

Variables	**Prominent partner in managing the coordination**	**Prominent partner in decision-making**
Prominent partner in decision-making	0.492***	
Publication restriction	0.084	0.188**

*p<0.10; **p <0.05; ***p<0.01

Phi coefficient was used to measure the association between dichotomous and categorical variables.

Table 3.4 provides an overview of the independent variables. As discussed in Section 3.2, we asked respondents to evaluate their Ph.D. projects in terms of three types of proximities and two types of resource indicators. For measuring geographical proximity, we considered whether the offices of university partners are located abroad or not (asking specifically whether the partner's offices were located in its supervisor's place of residence). Given the small size of the Netherlands, this variable captures geographical proximity as almost all Dutch cities can be reached within just two hours from Eindhoven. As can be seen in Table 3.4, the geographical distance is low in 163 cases, and high in 28 cases. Social distance is measured by observing whether the collaborating organizations had previous relationships, as discussed above. We see that for most cases, the social distance is low (i.e. there have been previous relationships); in only 33 cases is the social distance high. Finally, cognitive distance was measured by asking the respondents to rate the university supervisor's level of knowledge on the specific research topic (on a five point Likert-type scale), as well as that of the partner's supervisor, and then consider the distance between these two ratings. Hence, we measure cognitive distance in the vertical sense (how much more does one partner know about the specific topic than the other) instead of cognitive distance in the horizontal meaning (how different is the knowledge the partners hold), as other have done (e.g. Nooteboom *et al.*, 2007).

Table 3.4 Descriptive statistics of independent variables

Theoretical concept	**Independent variable**	**Values / mean**	**S.D.**	**Min**	**Max**	**N**
Geographical distance	Country of the offices of the main collaborating partner (where supervisor of collaborating partner was located) is abroad	The Netherlands: n=163 (85%) Abroad: n=28 (15%)				191
Social distance	No previous relationship between supervisors from both the university and its partner before Ph.D. project	Previous relationship: n=140 (81%) No previous relationship: n=33 (19%)				173
Cognitive distance	Differences between level of knowledge of university and its partner's supervisor	.73 (on a scale of 1-5)	.805	0	3	187
Critical resources	University holds critical resources	3.49 (on a scale of 1-5)	1.190	1	5	171
	Partner holds critical resources	3.39 (on a scale of 1-5)	1.092	1	5	169
Funding	Ph.D. project funder	Partner: n=109 (57%) University: n=14 (7%) Other: n=68 (36%)				191
Industry involvement	University's partner is a firm	Firm: n=103 (54%) PRO: n=88 (46%)				191

Our measurements for resource indicators are quite straightforward, simply asking the respondents to what degree either partner provided access to unique resources (where we provided a number of examples of such resources). For funding, we distinguish between projects funded by the partner, projects funded with the university's own budget, and 'other funds' (which notably include large public funding organizations such as the Dutch NWO and STW agencies, as well as personal scholarship).

We also measure industry involvement using a dummy, considering whether the university's partner is a firm (dummy=1) or a public research organization (PRO) (dummy=0). Out of 191 collaborations, 103 involved industry.

As part of our analysis, we also considered the effect of nine control variables. Table 3.5 presents these variables, which all relate to the motivation of the university or the partner to engage in the collaboration, and thus offer an alternative explanation of the phenomena we measured. (Below we provide more information on how we entered these control variables in our analyses.)

Table 3.5 Descriptive statistics of control variables

Control variable	Mean	S.D.	Min	Max	N
Motivation of collaborating partner:					
A need for a very specific piece of knowledge to fill an existing knowledge gap	3.58	1.154	1	5	174
A more general increase in the organization's longer-term stock of knowledge in a specific area	3.70	0.987	1	5	169
Promoting employee to obtain a Ph.D. (in cases where the Ph.D. candidate was employed by the collaborating partner prior to the Ph.D. project)	2.67	1.389	1	5	130
Creating and maintaining linkages to universities	3.73	.984	1	5	177
Motivation of university:					
Collaboration was required to obtain public funding	2.83	1.428	1	5	134
Attractiveness of research topic	3.94	.829	1	5	173
Alignment of university research with industry needs	3.57	1.170	1	5	172
Contributing to the regional or national economy	2.64	1.141	1	5	143
Creating and maintaining linkages to industry	3.74	1.116	1	5	170

All variables measured on a Likert-like scale ranging from 1 (strongly disagree) to 5 (strongly agree).

3.4. Results and discussion

Using binary logistic regressions, we tested our ten hypotheses for the effect of proximity and resource imbalances. A general overview of these regressions is shown in Table 3.6. Each of the Columns [1] to [6] has a different dependent variable relating to the governance mode, whereas for Column [7], the dependent variable is whether or not the partner imposed a publication restriction.

Table 3.6 Regression analysis of impact from proximity and resource variables on governance modes

Governance mode	Centralized	Centralized	Shared	Centralized	Centralized	Shared	
Model / Dependent variable	[1] University manages	[2] Partner manages	[3] Both manage	[4] University decides	[5] Partner decides	[6] Both decide	[7] Publication restriction
Distance variables							
Geographical distance	**1.115** (4.348)**	-.282 (.156)	**-1.050* (3.134)**	.741 (2.091)	.490 (.519)	**-1.148* (3.797)**	**1.545** (5.377)**
Social distance	-.614 (1.508)	-.529 (.666)	**.840* (3.191)**	.160 (.117)	**-1.419* (3.359)**	.456 (.926)	.290 (.192)
Cognitive distance	.054 (.056)	-.087 (.078)	-.041 (0.031)	.121 (.287)	.474 (2.350)	**-.437* (3.216)**	.531 (2.325)
Resource variables							
University holds critical resources	**.510*** (8.641)**	**-.632*** (9.793)**	-.058 (.136)	**.388** (5.592)**	**-.807*** (13.523)**	.138 (.716)	.056 (.053)
Partner holds critical resources	-.237 (1.696)	.344 (2.362)	.005 (.001)	-.232 (1.758)	**.473** (3.933)**	-.070 (.153)	.404 (1.851)
University funds the project itself	-.151 (.046)	-.883 (.574)	.782 (1.122)	1.036 (1.807)	-.833 (.501)	-.586 (.447)	**2.022* (3.144)**
Partner funds the project	**-1.168*** (8.323)**	.877 (2.732)	**.762* (3.425)**	-.613 (2.507)	.552 (1.005)	.398 (.981)	**1.182* (2.754)**
Other variables							
Industry involvement	.006 (.000)	**-1.247** (6.397)**	**.802** (4.012)**	**-.635* (2.962)**	-.780 (2.376)	**1.219*** (8.566)**	**1.899** (5.388)**
Control variables[(a)]	No	No	No	No	No	No	No
Model fit (Nagelkerke R^2)	R^2=.217	R^2=.201	R^2=.135	R^2=.180	R^2=.257	R^2=.167	R^2=.298
N	147	147	147	147	147	147	147

Significance levels: ***: 1%, **: 5%, *: 10%. All cells with 10% significance or better are shown in bold. Columns [1] to [7] are binary logit regressions. Note (a): Here, we show the regression results without considering the effect of our control variables. Below, we discuss the effect of control variables on the dependent variables.

Table 3.6 shows that geographical distance has a significantly negative impact on both shared project management and decision-making based on mutual agreement, supporting Hypothesis 1a. As argued before, we believe that this high geographical distance between the university and its partner reduces the level of trust due to less and less frequent interaction and face-to-face communication between them (Desrochers, 2001; Boschma, 2005; Ponds *et al.*, 2007). In these cases, the partners opted for centralized governance opposed to shared governance. Table 3.6 also shows that in such scenarios, the university is far more likely to perform the governance tasks than the partner. Perhaps this is because we also observed that the Ph.D. candidate in most cases resided at close proximity to the university (not separately reported in this paper); thus there is a low spatial distance between this candidate and the university – and a high spatial distance between this candidate and the partner.

Regarding Hypothesis 1b, we found that, contrary to our expectations, social distance has a positive effect on shared management. Hence, this hypothesis regarding shared mode of management is rejected. Possibly, and different from geographical and cognitive distance, social distance may be a possible reason for choosing shared governance as both partners still need to know each other. By contrast, when partners have collaboration experience (social proximity), they are more likely to trust each other already, and it may be more likely that one partner governs the collaboration on behalf of the both. Our results further indicate that social distance among partners also has positive effect on the shared decision-making, but not significantly so.

Regarding Hypothesis 1c, we found no significant effect of differences between the level of knowledge at the university and its partner's supervisors (cognitive distance) on shared management. However, our results show that cognitive distance has a significant negative impact on shared decision-making, meaning that Hypothesis 1c regarding shared decision-making is confirmed.

Continuing with the role resources play in the mode of governance, we conclude that decision-making is indeed strongly dependent on the ownership of critical resources, such as data or research facilities. This result confirms Hypothesis 2. If the university holds these resources, this also has a positive effect on its likelihood of managing the project, but the same does not apply to partners. The fact that most Ph.D. candidates were resident in Eindhoven (the city which university is located) during the Ph.D. projects, may further explain why especially the university tends to centralize the day-to-day management when holding critical resources. Concerning Hypothesis 3, funding by the university or its partner does not increase its likelihood to manage the project, nor to centralize decision-making. Hence, we find no support for this hypothesis.

Finally, we consider in what situations publication restrictions occur. Our results in Table 3.6, Column [7] show that industry involvement (meaning the university's partner is a firm as opposed to a PRO), renders publication restrictions more likely. This result supports Hypothesis 4. We believe the firm's focus may be predominantly commercialization activities, and in this case, the disclosure of output can run the risk of knowledge leaking to a firm's competitors.

Ownership of critical resources (Hypothesis 5a and Hypothesis 5b) has no effect on publication restrictions. Concerning funding, partner funding increases the likelihood of publication restrictions (confirming Hypothesis 6b), while university funding does not reduce this likelihood (rejecting Hypothesis 6a). That is, universities do not seem to defend an open publication attitude in such collaborations, even when they have the bargaining power to do so (by owning critical resources). This is in contrast to what we expected from a university's primary mission. Furthermore, as we mentioned, our results show that in cases where projects are funded by a partner or even by the university itself, publication restrictions increase. It is clear that in the first situation, the partner as a funder stays in power so imposes publication restrictions. However, in the second situation (university is a project funder), it seems that the university partner tries to maintain the power balance by placing restrictions. We need to stress, however, that regardless of the effects we found, publication restrictions remain rare, as can be seen in Table 3.6.

As there might be alternative explanations for the evaluated phenomena, we performed robustness checks by adding nine control variables, all relating to the motivation of either the university or the partner to collaborate (see Table 3.5). However, in order to prevent losing a degree of freedom unnecessarily, we opted to include the control variables one by one, each time checking whether the conclusions regarding the confirmed hypotheses were still valid. In our findings below, a high robustness score means that the initial effect also holds whatever control variable is added, and that the weaker the score, the more often the effect disappeared when one of the nine variables was added.

Table 3.7 shows an overview of the results of our robustness checks for each of the accepted hypotheses. As can be seen, the robustness scores do tend to vary. In particular, the effect of funds at the partner organization on the decision to restrict publication (Hypothesis 6b) can be said to be little robust, as this effect was only found in three of the nine regressions that included a control variable. The remaining hypotheses confirmed in the initial analysis were found to be robust in at least five out of nine regressions.

We also included the different university departments as additional variables to control for disciplinary differences (not separately reported in this paper). We did not find any difference between departments as after adding all departments one by one to our models.

Table 3.7 Overview of results for all hypotheses, including robustness checks (between brackets)

Dependent variable	**Shared management**	**Shared decision-making**
Hypothesis 1a: As the geographical distance between partners increases, a shared governance mode becomes *less* likely	**Confirmed (6)**	**Confirmed (6)**
Hypothesis 1b: As the social distance between partners increases, a shared governance mode becomes *less* likely	**Rejected**	No effect
Hypothesis 1c: As the cognitive distance between partners increases, a shared governance mode becomes *less* likely	No effect	**Confirmed (5)**
Hypothesis 2: If one of the partners holds critical resources, it is more likely to control the governance	**Confirmed for university (9) Rejected for industry**	**Confirmed for university (9) Confirmed for industry (7)**
Hypothesis 3: If one of the partners is the sole project funder, it is more likely to control the governance	No effect	No effect
Hypothesis 4: Industry involvement renders publication restriction *more* likely	**Confirmed (9)**	
Hypothesis 5a: If the university holds critical resources, publication restriction is *less* likely	No effect	
Hypothesis 5b: If the university's partner holds critical resources, publication restriction is *more* likely	No effect	
Hypothesis 6a: If the university is the sole project funder, publication restriction is *less* likely	**Rejected**	
Hypothesis 6b: If the university's partner is the sole project funder, publication restriction is *more* likely	**Confirmed (3)**	

3.5. Conclusions, implications and future research

Our empirical study adds to the burgeoning field of university-industry relations in two ways. First, it deals with joint Ph.D. projects, which is a seriously underexplored topic in this area. Hitherto, the main focus has been on university patenting and licensing and on university spinoffs. However, as stressed recently by Perkmann *et al.* (2013), the "academic engagement" of universities towards industry is much more varied and multifaceted, and includes, among other channels, joint Ph.D. projects. Our study aimed to fill this gap by investigating the conditions that affect the governance mode choice in joint Ph.D. projects. Second, we have gone beyond previous statistical studies on university-industry relations, which only tested whether various forms of proximity affect the *number* of university-industry collaborations (Ponds *et al.,* 2007; Balland 2012; Bouba-Olga *et al.,* 2012 and D'Este *et al.,* 2013). We looked, instead, into the nature of university-industry collaborations by distinguishing various governance modes. In doing so, we could investigate whether shared governance modes are more likely among proximate partners.

In summary, this study finds three main robust results, which confirmed our hypotheses: (i) geographical distance renders the choice for shared management and shared decision-making less likely; (ii) the partner controlling critical project resources tends to centralize project governance, and (iii) partnering firms are more likely to put restrictions on publication output than public research organizations. We further found that, as expected, cognitive distance rendered shared decision-making less likely, but no such effect was found on shared management. Regarding social distance, we found that – unexpectedly – it increased the likelihood of shared management. No effect of social distance on shared decision-making was found.

We believe our conclusions have implications not only for universities wanting to improve the performance of collaborations, but also for their partners. As earlier research (Salimi *et al.,* 2013, Chapter 4) has shown that projects adopting a shared governance are more successful than those adopting a centralized governance mode, one may consider the conditions that favor shared governance in future project selections. As geographical and cognitive distance make the adoption of a shared mode of decision-making less likely, universities are recommended to either: (i) be selective in choosing collaborations and favor those collaborations where partners are located nearby and have a similar knowledge level, or (ii) not to select on the aforementioned aspects, but insist on having a shared governance by sharing both decision-making and project management tasks, even though that might require additional investments in time and resources from both collaborators. Furthermore, we believe that when it comes to accepting publication restrictions, universities could be more critical than they are at present. While universities may not always be in a position to bargain, they can certainly do so if they have critical resources. Our results show that even in such cases, universities often do not make use of their bargaining power to ensure open publication.

Our recommendations to universities' partners (firms and public research organizations) mirror to a large degree our recommendations for universities. We advise them to seek collaboration with universities that are located relatively nearby. Given our findings that with long-distance collaboration, the Ph.D. candidate usually resides close to the university anyway, choosing a near-by university provides other advantages also to the partner. If one, nevertheless, enters into a long-distance collaboration (for instance because the institute located further away is more attractive in terms of its expertise), then the partner should be willing to spend additional resources and time to ensure that shared governance is achieved, thus improving the chances of high output. Concerning cognitive proximity, the implication for partners would be to allocate supervisors who have a knowledge level on the specific topic that is roughly in the same range as that of the allocated university supervisor. In that case, a shared governance mode becomes more likely and this in turn affects the probability of a project's success.

Our study has a number of limitations, some of which suggest avenues for further research. To begin with, all our cases are from one single university (Eindhoven University of Technology). Even though this university has no strict guidelines on Ph.D. collaborations, with faculty members having a large degree of freedom to design their collaborations, we cannot exclude some aspects being university-specific. In order to be able to generalize this for other institutions, other national contexts, and other disciplines, we hope future studies can test our findings in different settings. Regarding the national setting, we have operationalized our geographical distance as whether both collaborative partners were located in the Netherlands, or not. Given the small size of the Netherlands, we regard this as an obvious choice, since all distances between the university and national partners can easily be travelled within one working day. In a larger country, however, the longer distances could have quite different implications, and more refined conceptualizations of distance could be explored. A further limitation is that we have only considered successfully concluded Ph.D. studies, where success is defined as the Ph.D. candidate receiving the doctoral degree. We have not explored the relationship between governance modes and the likelihood of Ph.D. collaborations failing prematurely, for whatever reason. A study on Ph.D. failures in the context of collaborations could extend our understanding of this area. In this study we considered the characteristics of university and its partner such as cognitive differences, and social differences between them. However, characteristics of Ph.D. candidates in collaborative Ph.D. projects, and their proximity to the university and partner supervisors, may also influence the mode of governance. Furthermore, creation of knowledge requires different and complementary knowledge, which is the source of novelty and creativity (Boschma, 2005). The investigation of effect of different and complementary knowledge of partners on the governance choices compared to the effect of similar knowledge base among partners on governance would deserves consideration. Moreover, considering other government bodies and universities would be interesting and deserves attention as one of the valuable future research in this filed. Finally, while we restricted ourselves to collaborative Ph.D. projects, future studies exploring governance modes across other types of collaborations (like R&D) could complement the current insights.

4. Governance and success of university-industry collaborations on the basis of Ph.D. projects – an explorative study[1]

Abstract

Faced with ever-increasing pressure to innovate and perform well, firms consider universities as significant external sources of knowledge. Such knowledge flow can take place in a variety of ways such as academic publications, contract research, staff mobility and university patents and licenses, but also more collaborative modes such as joint research projects. This paper focuses on a specific – and important – collaborative model, in which firms and universities are involved together in a Ph.D. project, carried out by a doctoral candidate. We analyse the effects of various aspects of governance on the success of collaboration. Here, success is operationalized in various ways, including publishing, patenting and the successful transfer, application and commercialization of knowledge. We tested our model using a survey conducted at Eindhoven University of Technology (TU/e) in

[1] This chapter is based on:
Salimi, N., Bekkers, R., Frenken, K. (2013). Governance and success of university-industry collaborations on the basis of Ph. D. projects: an explorative study. Submitted to *Research Policy* (now in the second round of review).
Earlier versions of this paper were presented at a research seminar held at Eindhoven University of Technology's department of Industrial Engineering and Innovation Sciences and at a colloquium at Delft University of Technology.

the Netherlands. We conclude that governance decisions have a significant impact on the ultimate success of a project. Among other things, the choice of university supervisor plays a pivotal role. Moreover, success is more likely if there is joint decision-making by both university and partner on the content of the project, and if communication between the Ph.D. candidate and the supervisor in the firm is frequent and of high quality. We believe our findings can help universities and firms to collaborate successfully.

***Keywords*:** collaborative Ph.D. projects; governance of university-industry collaborations; collaboration success

4.1. Introduction

In the past decade, there has been considerable evidence illustrating an increase in linkages between universities and industry including the growing propensity of universities to patent (Nelson, 2001), universities' growing licensing revenues (Thursby *et al.*, 2001), an increasing number of university spin-offs (Shane, 2005), and increasing number of science parks (Siegel *et al.*, 2003b). Knowledge transfer from university to industry can occur through different channels. There is already considerable literature on the topic of knowledge transfer from university to industry, but most of that literature is focused on formal, non-collaborative forms – such as patenting – even though recent studies highlight the importance of collaborative forms (e.g. Bekkers and Bodas Freitas, 2008). Going beyond mere commercialization of academic knowledge, Perkmann *et al.* (2013) introduce the concept of academic engagement, defined as "knowledge related collaboration by academic researchers with non-academic organizations". This definition includes differentiated forms of interaction, from formal activities such as collaborative research, contract research and consulting, to informal activities like meetings or attending conferences (D'Este and Patel, 2007; Grimpe and Hussinger, 2013).

While collaborative research projects can be conducted in various forms, one interesting way to collaborate is via a Ph.D. project, carried out by a doctoral candidate. Doctoral candidates are not only key producers of new knowledge but potentially also important channels for transferring such knowledge to firms (Thune, 2009). One interesting aspect of this type of collaborations is that there are three central actors: the firm, the university, and the doctoral candidate (i.e. the individual who is enrolled full or part-time in a program leading to a doctoral degree). Here, we define a collaborative Ph.D. project as *"a project with a typical duration of 3-4 years and which involves a university, a firm, and a Ph.D. candidate, all working together to meet (common or individual) expectations."*

Despite evidence of increasing trends in collaboration between university and industry, success is by no means guaranteed. Various factors can cause collaborations to fail such as choosing an inappropriate partner for collaboration (Beamish and Inkpen, 1995), coping with management issues (Dodgson, 1991; Kelly *et al*., 2002) and communication problems (Kelly *et al*., 2002). Collaboration is inherently a costly and risky activity and all partners invest in collaboration by consuming budgets, time and resources. In this study our focus is on governance, which we believe to be one of the important aspects that impacts the success of university and industry collaboration. Williamson (1973) identified two types of governance: market governance and non-market governance. In the first type of governance, transactions are only conducted at arm's length. A firm can for instance purchase knowledge through market transactions (e.g. consultancy, license agreements) or develop knowledge in-house through R&D investment. If transaction costs are relatively high, a firm will opt for in-house production instead of market transaction. Transaction-specific assets, uncertainty and transaction frequency have made non-market governance more efficient than market transaction (Williamson, 1973, 1985). In non-market governance, transactions are centered on inter-organizational collaboration, which is based on trust, mutual understanding, joint action and parallel expectation among partners (Steenkamp and Geyskens, 2012). By considering industry collaborating with university in order to produce or acquire knowledge, in this study we refer to the non-market governance mode with specific characteristics mainly relating to how partners manage their relationship, make decisions on the content of collaboration and communicate with each other (Artz and Brush, 2000).

In collaborations involving two diverse organizations with different cultures, goals and incentives, success depends on the management effort (Dodgson, 1991). More precisely, entering into the collaboration requires important decisions in terms of funding the project, the content of the project and managing the day-to-day relationships, all of which can cause a collaboration to succeed or fail. The actual benefits of joint research collaboration are derived under a well-defined governance structure (Jung *et al*., 2010; Morandi, 2013). Therefore, it is clearly essential for both university and industry to maximize the benefit of collaboration through effective governance. However, the existing literature concerning the governance of university and industry collaborations is very limited (see, for instance, Morandi, 2013).

This paper aims to investigate the effect of governance characteristics on the success of collaboration between university and industry through Ph.D. projects, trying to identify the main determinants of success. We believe that this paper contributes to the literature in three ways. Firstly, it fills the existing gap in the area of university-industry collaboration governance. Secondly, it is one of the very few contributions that focuses on collaborative Ph.D. projects. Such collaborations are quite common, especially at technical universities: as we will show later, in the university where we collected our data, almost one third of all 1783 doctoral theses published between 2000 and 2011 were the result of a collaboration. Still, this form of collaboration is almost completely overlooked in the literature on university-industry collaboration. Thirdly, we measured the success of collaboration as a multi-dimensional concept whereas in the literature, the success of university-industry collaboration is considered a one-dimensional concept (see Butcher and Jeffrey, 2007).

We believe that this study, in addition to its scientific contributions, has several practical implications, not only for universities, but also for their partners in industry, that could increase the chance of collaboration success. More precisely, governance structure acts as a tool for university and industry to benefit from collaboration, which inherently consumes many resources.

The remainder of this paper is organized as follows. In Section 4.2, we review the literature on collaboration governance and its characteristics, as well as the literature on measuring collaboration success. In Section 4.3 we propose a methodology to investigate the relationship between governance characteristics and successful collaboration. Then, in Section 4.4, we present our empirical analysis and discuss the findings. The paper ends with conclusions, managerial implications and future research directions (Section 4.5).

4.2. Governance and success of collaborative Ph.D. projects

By reviewing the existing literature, we can identify the characteristics of governance in collaborative Ph.D. projects (Section 4.2.1) and the success measurements of this type of collaboration (Section 4.2.2).

4.2.1. Governance of collaborative projects

The governance of collaboration may influence a firm’s innovative performance (Jung *et al.*, 2010). In the literature, governance is considered as one dimension of collaboration and is studied from different angles (Thomson and Perry, 2006). One aspect of governance emphasizes the joint action and behaviour among collaborative partners. Based on this view, partners who become involved in collaboration must learn how to manage their relationships in order to make joint decisions, as well as find a way to solve problems and conflicts (Artz and Brush, 2000). In that sense, the significant governance characteristics of a collaboration include: who had the initial idea for the collaboration (Bekkers and Bodas Freitas, 2011), who is most prominent in managing the relationship (Butcher and Jeffrey, 2007) and how are risks or rewards shared (Ostrom, 1990; Lambert, 2008).

Thomson and Perry (2006) believe that governance is at the ‘heart of collaboration”, focusing on the negotiation between, and commitment of, partners. In order to achieve joint management and decision-making among partners, trust (Ostrom, 1990; Lambert, 2008) and commitment (Mattessich and Monsey, 1992; Barnes *et al*., 2002; Lambert, 2008) can be seen as necessary conditions. These aspects of governance can be created by maintaining close relationships and good communication between partners (Mattessich and Monsey, 1992; Lambert, 2008).

Governance is also related to the arrangement for achieving a balance between the goals and the benefits to universities and industry, as well as their participation in managing the relationships (Foray and Steinmueller, 2003). In other words, although governance is sometimes referred to as joint decision-making (McCaffrey *et al*., 1995), joint problem solving (Artz and Brush, 2000), reciprocal perception and understanding of drivers, needs and interests (van Gils, 2012) and a shared power arrangement (Crosby and Bryson, 2005), it is at the same time based on negotiation and on respecting the other’s opinion (Thomson and Perry, 2006). That is, parties must agree to collaborate under conditions that are not necessarily in their best interest (Thomson and Perry, 2006).

By means of these explanations, we define the governance of collaboration as an arrangement between partners in order to benefit from collaboration. This arrangement covers different aspects of collaboration such as how the partners' relationship is managed, how decisions are made on the content of projects, how partners communicate with each other and achieve a balance between their goals and benefits.

In this study, we wanted to open up the governance black box, to understand what elements form the core of collaboration governance and how actors make decisions and govern their relationships. In doing so, we not only adopted findings in the related literature of university-industry collaboration (see previous paragraphs) but also combined these with three main categories to study the effectiveness of collaborative research as proposed by Butcher and Jeffrey (2007).

As we focused on a very specific type of collaboration between university and industry involving Ph.D. candidates, the offered governance structure covers more aspects of governance that can affect success. More precisely, based on the first aspect of governance, we identified project management characteristics such as which partner(s) is responsible for funding the project, managing the coordination, making decisions on the content of project, and if any publication is prohibited due to industry restrictions. With respect to the second aspect of governance, we considered the communication characteristics between partners in a collaborative Ph.D. project. We measured this aspect by considering the quality and frequency of meetings between Ph.D. candidates and their supervisors both at the university and at the partner as well as between the supervisors in both locations. Because of the important role that supervisors play in collaborative Ph.D. projects, we considered supervision characteristics a third aspect of governance. This aspect is measured by various characteristics such as both the university supervisor and its partner supervisor's level of knowledge on the Ph.D. topic, the enthusiasm of both supervisors to be involved in the project, their level of openness to any new ideas and similar opinions between both supervisors on the Ph.D. topic. Further factors which we considered can impact on the success of collaborative Ph.D. projects are: the effect of the university supervisors' academic position, the industry supervisors' academic degree and the replacement of any of the supervisors during the Ph.D. project.

4.2.2. Success of collaborative Ph.D. projects

An important aspect of our model is determining the collaboration's success. We should stress that in this study, success refers to the extent to which the collaboration's goals are met. Here, the view of collaboration is based on "civic republicanism", so that despite existing differences, actors collaborate to achieve mutual understanding, trust, and implementation of shared preferences (March and Olsen, 1989). We do, however, acknowledge that each partner may have their own interpretation of the collaborative achievement. This interpretation is called satisfaction and can be distinguished from the success seen in Behrens and Gray's (2001) work[1] in which they state that a collaborative project is successful if all the partners are satisfied with the collaboration. The basis of their perspective is "classic liberalism", whereby each actor engages in the collaboration to achieve their own goals and interests without considering other actors' preferences (Thomson and Perry, 2006).

In the extant literature, measuring the success of collaborations between university and industry based on various dimensions has been unfairly neglected. Some studies only rely on finding those factors which influence the success of university and industry collaboration without measuring what that success actually entails. For instance, Butcher and Jeffrey (2007) investigated the

[1] Behrens and Gray's (2001) consider the success of collaborations involving projects carried out by graduated students including (but not only) Ph.D. candidates.

correlation between collaboration success factors such as supervisor, project management and communication and the perceived collaborative research success (from the Ph.D. candidate's perspective). Unfortunately, however, these researchers did not consider different dimensions when measuring collaboration success. Other studies measure success from a single dimension only, such as knowledge transferring ability between partners, development and commercialization of a new product (Bekkers and Bodas Freitas, 2011). Siegel *et al*. (2003a) identify how technology as one output of university-industry collaboration is successfully transferred and the strategies for improving technology transfer. This type of literature views success as a one-dimensional construct. However, other researchers conceptually mention different dimensions for the success of university-industry collaboration without considering these different dimensions in their analyses. They consider success as merely a single concept, which we believe cannot provide useful results in this field. For instance Santoro (2000) mentions that tangible technological outcomes (e.g. publication, patent, patent application) along with knowledge sharing are measurements of success in university-industry collaborations. Barnes *et al*. (2002) also identified success as a multi-dimensional construct. They evaluate six collaborative research projects between university and industry and identify different measurements for collaboration success. They evaluated the projects' outcomes based on two types of measurement: subjective and objective. For their subjective evaluation, they relied on the main participant's perception to the extent their expectations were met. In terms of objective success measurements, they considered the number of publications, patents, new product, new process and technology development. However, their work is a conceptual study based on six case studies.

As success is multi-dimensional, it is more logical and beneficial for us to investigate the effects of a variety of governance characteristics on different dimensions of success.

While focusing specifically on collaborative Ph.D. projects and studying the existing literature, we aimed to consider all the relevant dimensions of success.

Collaboration success can be measured by collecting data from one of the collaboration partners (industry, university, Ph.D. candidate) and in an ideal situation, from all partners. Partners may differ in their evaluation of the success of the collaboration, depending on their perspective (Bekkers and Bodas Freitas, 2011). In this study, although the data has been collected through Ph.D. candidates, we considered all the partners' perspectives. Barnes *et al*. (2002) show that a Ph.D. candidate's opinion and experiences as a main actor in the collaborative project give us access to both the industry and academia perspective. In addition to the Ph.D. candidate's pivotal role in the collaboration, the easier accessibility of Ph.D. candidates is also relevant from a practical viewpoint. Finding the supervisor(s) at a university and the contact person in industry is very difficult compared to tracking down a Ph.D. candidate, even if that person graduated as long as 10 years ago. It is clear that in most cases, the Ph.D. project is the only special project such a candidate has worked on during a three to four year period, whereas the same project may be only one of many with which a university or firm supervisor is involved. Finally, because it is the Ph.D. candidate who actually conducted the research rather than the supervisors, the data obtained from a Ph.D. candidate are likely to be more reliable than data obtained from supervisors (Behrens and Gray, 2001). Other studies like those of Butcher and Jeffrey (2007) also evaluated collaborative projects in terms of being successful or unsuccessful from the Ph.D. candidate's perspective due to considerations about response rate and quality of responses. Therefore in terms of subjective evaluation for this study, the measurement of collaboration success depends on the Ph.D. candidate's perception and experience.

Wherever possible when evaluating collaboration, we used factual, objective measurements by considering all relevant success measurements such as academic publication track records and patents resulting from the project (Barnes *et al.*, 2002). We also measured the level of knowledge transfer, absorbed, applied, or commercialized (Bekkers and Bodas Freitas, 2011). The extent to which the knowledge Ph.D. candidates developed in their theses has been adopted by industry is measured in a progressive scale. In the early preliminary stages, this knowledge may not be transferred at all. The next stage, knowledge transfer, makes that knowledge effectively available to industry staff working in this field and for instance accessible in libraries or being presented to staff. Once industry researchers have studied and mastered the transferred knowledge, absorption has taken place. The next stage occurs when the absorbed knowledge is applied in a business context. The final step is commercialization, which can be a small part or form of a product or process.

Furthermore we measured whether the relationship between university and partner was continued (van Gils, 2012). By this we mean that if, after finalizing the Ph.D. project, the university and the partner become engaged in a new collaboration. Other consequences of collaborative Ph.D. projects can be whether the university or partner offered the Ph.D. candidate a job after graduation. As such, we considered a job offer to a Ph.D. candidate from a university or its partner a proxy of a successful collaboration.

In sum, we use the three collaboration dimensions as governance characteristics and analyse their effect on six different success indicators. Figure 4.1 provides a schematic illustration of our approach.

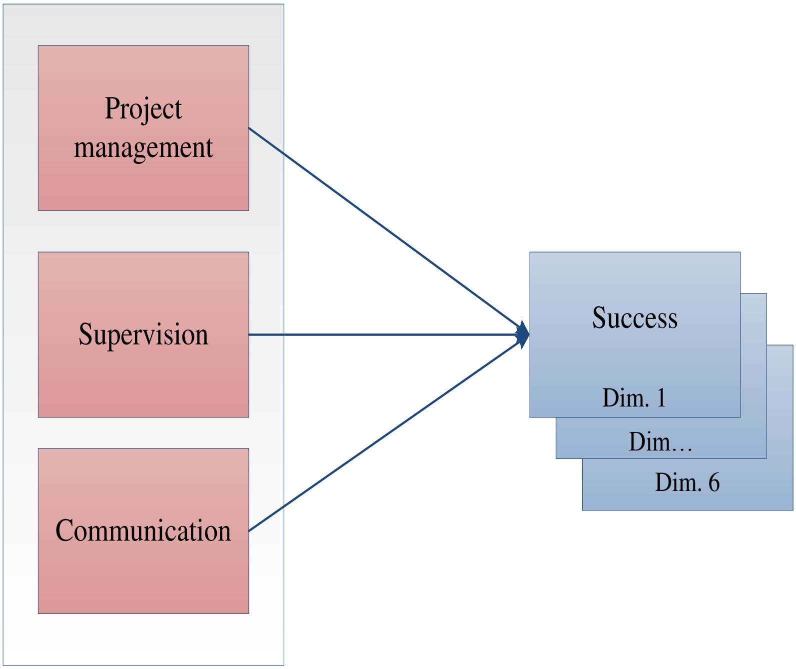

Figure 4.1 A model of collaborative Ph.D. project governance

4.3. Data and methodology

4.3.1. Data collection

We conducted a survey in order to examine how university and industry build their relationships through collaborative Ph.D. projects and how different governance characteristics impact on different collaboration success measurements. In our study, the collaborative Ph.D. project is the unit of analysis. Our population is defined as Ph.D. projects involving Eindhoven University of Technology (henceforth indicated by TU/e) and a firm or public research organization (PRO) that resulted in a published Ph.D. thesis between the years 2000 and 2011.[1] Here, it is important to

[1] We include all departments of the university, which include Applied Physics, Chemical Engineering and Chemistry, Electrical Engineering, Mathematics and

stress that in The Netherlands, most of the public research organizations rely heavily on contract research and other sources of commercial funding, and have very limited public funding, quite differently from PROs in many other countries that are much closer to government agencies.[1] There is a specific reason why we decided to collect data for our study at a technical university: as argued by Stephan *et al.* (2004), doctoral education in science and engineering is critical to the role universities play in fostering economic development. Therefore we are much more likely to find this type of collaboration (industry-university) in technical rather than other universities.

Taking all 1783 doctoral theses published between 2000 and 2011 by the TU/e as a starting point, we determined that 496 (28 percent) of all Ph.D. theses resulted from a collaboration with a firm or public research organization (in this paper we call these ‘collaborating partner’ or simply ‘partner’). For 408 of these, we were able to retrieve up-to-date contact details of the former Ph.D. candidate. We then approached the full population of 408 former Ph.D. candidates. Data acquisition took place between January and April 2012. After sending two reminders, we received a total of 191 complete and valid responses, of which 103 represented collaboration with firms and 88 with public research organizations, bringing our overall response rate to 47 percent.

As explained above, we sent the questionnaire to (former) Ph.D. candidates, not to the university supervisor or the collaboration

Computer Science, Mechanical Engineering, Built Environment, Biomedical Engineering, Industrial Design, and Industrial Engineering and Innovation Sciences. The latter four departments, the departments with a low number of respondents, are grouped into a single category in the regression analysis to avoid dummy values to be affected too much by outliers. We label the single category Management/Design (although we understand that this label does not cover the Biomedical Engineering department well).

[1] In that sense, their behavior is not so different from firms in the context of our study (Bienkowska *et al*., 2010). We did use a control variable, though, to see whether our findings for public research organizations differ from those for firms (see Section 4.3.2).

partner's supervisor. One of the advantages is that these individuals were deeply involved (usually spending a full 4 years of their life on this project) and are likely to recall aspects of the collaboration very well, also because it was a one-time event for them. The supervisors, in contrast, may have supervised many projects and may not recall all aspects of a specific project that well. Furthermore, if we would require all the partners' opinions on a specific project, the response rate would decrease dramatically, thus hampering the data analysis.[1]

Still, measuring from a single source may cause concern in terms of common method variance. To reduce such bias as much as possible, we implemented measures as suggested by Podsakoff *et al*. (2003). Among other things, we designed the survey questionnaire with differently formatted responses (e.g. Likert scale, ordinal, categorical, and dichotomous). Having tried out the draft questionnaire in a pilot test, and based on the respondents' feedback, we improved the text. In particular, we addressed any perceived ambiguity, removed some concepts that were found to be vague, defined unfamiliar terms, and added examples. Apart from all these solutions, and to ensure there would be no common method bias, after conducting our survey, we used Harman's one-factor test. This technique involves all the (independent and dependent) variables being entered into an exploratory factor analysis (Podsakoff *et al*., 2003). Based on the result of the factor analysis, 13 factors were extracted, accounting for 71.8 percent of the total variance (the first factor accounts for 11.5 percent of the

[1] More specifically, if the probability of getting a response from each actor (Ph.D. candidate, university and collaborating partner supervisors) is Ri, then the probability of getting a sample of completed questionnaires from all three actors would be $R_{Ph.D.} \times R_{collaborating\ partner} \times R_{university}$. For example, assuming that the probability of getting a response (response rate) from each actor is 40 percent and fully independent of each other, the probability of obtaining a sample of completed questionnaires from all three actors would be $0.4 \times 0.4 \times 0.4 = 0.064$, which we call the combined response rate.

total variance). This suggests that our study does not suffer from common method bias.

Finally, to check for non-response bias, we used the projected respondent method offered by Armstrong and Overton (1977). This method assumes that non-respondents are more similar to late respondents. We compared non-respondents with two waves of respondents and found no indications of non-response bias.

4.3.2. Variables

Table 4.1 provides an overview of the dependent variables for this study. We measured success in different ways. The first – and perhaps the most important – measurement was of the level of knowledge actually transferred to and used by the partner. This measurement uses a progressive, ordinal scale as specified in Table 4.1, for which we applied the ordinal logit model in analysis (for the construction of this variable, see also Section 4.2.2). Our other success variables are dichotomous variables of whether a project resulted in academic publication, whether knowledge was patented, whether the university offered the candidate a job after the end of the project, whether the partner did so, and whether the relationship between the university and partner was continued. We used a binary logit model to analyse these dichotomous variables. Details on our dependent variables, including the phrasing of the underlying question in our survey, are in Table A in the appendix.

Table 4.1 Descriptive statistics of dependent variables

Dependent variable	**Values**	**N**
Level of knowledge transfer to partner	Not transferred at all: n=20 (11%) Transferred[(a)] : n=78 (41%) Absorption[(b)]: n=46 (24%) Application[(c)]: n=25 (13%) Commercialization as a smaller element of product or process: n=12 (6%) Commercialization as the main basis of product or process: n=8 (4%)	189
Resulted in academic publication[(d)]	Yes: n=168 (89%)	189
Knowledge was patented[(e)]	Yes: n=48 (25%)	189
Subsequent job offer from university	Yes: n=41 (22%)	189
Subsequent job offer from partner	Yes: n=60 (32%)	189
Collaboration was followed up	Yes: n=129 (81%)	160

(a): knowledge is now effectively available to the staff of the collaborating partner working in this field. It is for instance available in the library, or there has been a presentation; (b) the collaborating partner's researchers have studied and now master this knowledge; (c) the knowledge is being used by the collaborating partner in a business context; (d) the Ph.D. project resulted directly in publications in academic journals (either during or after finalization); (e) the Ph.D. project resulted in one or more patents or patent applications, with the Ph.D. candidate listed as inventor.

Table 4.2 reports the correlation between dependent variables. For the correlation between the first dependent variable (level of knowledge transfer) and other dependent variables, we used the Mann-Whitney test and the Phi coefficient for the remaining variables. As we can see from the table, almost all the correlations are very low, suggesting a high discriminate validity (Hair *et al.*, 2006).

Table 4.2 Correlation between dependent variables

Variables	Level of Knowledge transfer[1]	Resulted in academic publication[2]	Knowledge was patented[2]	Subsequent job offer from university[2]	Subsequent job offer from partner[2]
Resulted in academic publication	1795.5				
Knowledge was patented	2842*	-.080			
Subsequent job offer from university	2825	.039	-.101		
Subsequent job offer from partner	2575.5***	.010	.098	-.056	
Collaboration was followed up	1966.500	-.024	-.002	.081	-.018

*p<0.10; **p <0.05; ***p<0.01

1. Mann-Whitney test was used to measure the association between this ordinal variable and other dependent variables.
2. Phi coefficient was used to measure the association between dichotomous variables.

Table 4.3 is an overview of the independent variables. As discussed in Section 4.2.2, we asked respondents to evaluate their Ph.D. projects in terms of “project management”, “characteristics of supervisor” and “communication”. All continuous variables were measured on a five point Likert-type scale. Details on our independent variables, including the phrasing of the underlying questions in our survey, can be found in Table B in the appendix.

Table 4.3 Descriptive statistics of independent variables

Independent variable	Values / mean	S.D	Min	Max	N
Project management aspects:					
Ph.D. project funder	Collaborating partner: n=109 (57%) Others: n=82 (43%)				191
Prominent partner in managing the coordination	The university: n=88 (46%) The collaborating partner: n=38 (20%) Both partners: n=65 (34%)				191
Type of decision-making between both partners	By the university: n=93 (49%) By the collaborating partner: n=37 (19%) Both partners: n=61 (32%)				191
Publication was prohibited due to partner's restrictions	Yes: n=19 (10%)				191
Characteristics of supervisor:					
Academic position of the university daily supervisor	Assistant professor: n=92 (48%) Associate professor: n= 51 (27%) Full professor: n=48 (25%)				191
Academic degree of the partner daily supervisor	Bachelor or Master: n=23 (12%) Ph.D.: n=88 (46%) Assistant/associate/full professor: n=80 (42%)				191
Level of university supervisor's knowledge in Ph.D. topic	4.0785	.894	1	5	191
Level of partner supervisor's knowledge in Ph.D. topic	3.9144	1.156	1	5	187
Level of university supervisor's enthusiasm in Ph.D. topic	4.2094	.869	1	5	191
Level of partner supervisor's enthusiasm in Ph.D. topic	3.8871	1.130	1	5	186
Similar opinion between university and partner supervisors on Ph.D. topic	3.5225	1.218	1	5	178
Replacing any of the supervisors during the Ph.D. project	Yes: n=32 (17%) No: n=159 (83%)				191

Openness of university supervisor to any idea	4.0160	.904	1	5	188
Openness of partner supervisor to any idea	3.7104	1.031	1	5	183
Characteristics of communication:					
Meeting frequency of Ph.D. candidate and university supervisor	4.8848	1.475	1	7	191
Meeting frequency of Ph.D. candidate and partner supervisor	3.8953	1.903	1	7	191
Meeting frequency of both supervisors	3.2670	1.383	1	5	191
Quality of communication between Ph.D. candidate and university supervisor	4.0209	.978	1	7	191
Quality of communication between Ph.D. candidate and partner supervisor	3.6754	1.218	1	7	191

We further considered the effect of five control variables for an alternative explanation of the phenomena measured. These control variables are: (1) whether the partner's office is in the same city as the university, (2) whether the collaboration is with a public research organization (as opposed to a firm), (3) whether the Ph.D. candidate is a former employee of the partner, and (4) whether TU/e and the partner have a prior relationship. All these variables reflect a form of proximity between partners (Boschma, 2005; Ponds *et al*., 2007; Balland, 2012), including geography proximity (1), institutional proximity (2) and social proximity (3 and 4). In all cases, one can expect that proximity is supportive of trust, which benefits the complex coordination process. Hence, one expects positive signs for all four control variables. Finally, we use dummies for each university department to control for structural differences across disciplines. Details on our control variables, including the phrasing of the underlying questions in our survey, can be found in Table C in the appendix. Table D (also in the Appendix), which provides the correlation between all the independent and control variables, shows that these correlations are quite low. We assessed the potential multicollinearity between independent variables in each of the three regression models. In the first model below (the effect of project management on success), the variance inflation factor (VIF) is between 1.035 and 2.009. That is, the tolerance (1/VIF) is greater than 0.4, well above the critical value of 0.2 (Menard, 1995). With respect to our second model (the effect of supervisors on success), VIF is between 1.091 and 1.884 (equivalent to tolerances greater than 0.5). For the last model (the effect of communication on success), VIF is between 1.186 and 1.466, which means that the tolerance is greater than 0.6. These results suggest that our study does not suffer from multicollinearity. Furthermore we investigated the multicollinearity between all independent variables (see Section 4.4.4).

4.4. Results and discussion

As discussed above, we distinguished three groups of governance aspects: project management, supervision, and communication. Our main results for these groups are shown in Tables 4.4, 4.5 and 4.6 respectively (and discussed Section 4.4.1, Section 4.4.2 and Section 4.4.3 respectively). In each table we have two columns for every dependent variable, one without the control variables (see previous section), and one with these variables. Our discussion of the results will be solely based on the regressions including the control variables, as these are most reliable.

4.4.1. How does project management affect collaboration success?

We will discuss the findings of our analysis, starting with how project management is related to our various measurements of collaborative success (see Table 4.4).

The first dependent variable is the *level of knowledge transfer* (Table 4.4, Columns 1 and 2). As discussed earlier, this is an ordinal variable, for which we use the ordinal logit model. We found that knowledge transfer is supported by joint decision-making suggesting that joint involvement in the content part of a project is indeed helpful for knowledge transfer. Knowledge transfer is also supported by a publication restriction imposed by the partner. Arguably, this is because such cases represent strategic knowledge that the partner is keen to obtain (and keen to patent; see below). In terms of our control variables, we find that a former employee of the partner is more effective in transferring knowledge than other Ph.D. candidates, probably because of the familiarity of the candidate with the organizational context in which (she) he operates.

Table 4.4 Regression analysis of how different measurements of collaboration success (dependent variables) are impacted by project management aspects

	Level of knowledge transfer [1,2]		**Resulted in academic publication [3,4]**		**Knowledge was patented [5,6]**	
Funding funded by partner	-.160 (.334)	-.418 (1.871)	-.095 (.041)	-.172 (.110)	**.865** (5.188)**	**1.121** (5.962)**
Relationship managed by partner (1)	-.462 (.957)	-.426 (.725)	.499 (.360)	.343 (.136)	-.581 (.819)	-1.212 (2.389)
Relationship managed by both (1)	.253 (.583)	447 (1.540)	.035 (.004)	.396 (.429)	-.144 (.109)	**-.998* (3.576)**
Decision-making by partner (2)	**.947** (3.998)**	.362 (.484)	-.656 (.686)	-.093 (.010)	.443 (.509)	.873 (1.199)
Decision-making by both (2)	**.998** (8.866)**	**.682* (3.523)**	-.483 (.771)	-.133 (.049)	.062 (.020)	.045 (.007)
Publication restriction imposed by partner	.724 (2.609)	**.917* (3.714)**	-.177 (.065)	.493 (.385)	**1.202** (5.347)**	**1.202** (4.179)**
Partner's office in same city as university		-.399 (1.631)		-.767 (2.209)		**1.232** (7.571)**
Collaboration with public research organization (as opposed to firm)		-.437 (1.931)		.944 (2.657)		**-1.194** (6.062)**
Ph.D. candidate is former employee of partner		**1.172** (5.902)**		.445 (.266)		.123 (.035)
Prior relation between TU/e and partner		.089 (.057)		.834 (1.866)		-.714 (2.002)
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2=.103	R^2=.195	R^2=.016	R^2=.184	R^2=.103	R^2=.292

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. Columns [1,2] are ordinal logit regressions; all others are binary logit regressions. Note: (1) Baseline is relationship managed by university. (2) Baseline is decision-making by university.

Table 4.4 – Continued

	Subsequent job offer from university [7,8]		**Subsequent job offer from partner [9,10]**		**Collaboration was followed up [11,12]**	
Funding funded by partner	-.241 (.414)	-.295 (.514)	.372 (1.245)	.348 (.876)	**.740*** **(3.026)**	**.880*** **(3.018)**
Relationship managed by partner (1)	**-2.372**** **(7.660)**	**-2.496**** **(7.729)**	.267 (.233)	.276 (.211)	-.184 (.063)	-.265 (.101)
Relationship managed by both (1)	**-.962**** **(4.143)**	**-1.064**** **(4.330)**	.578 (2.195)	.414 (.933)	-.028 (.003)	.148 (.056)
Decision-making by partner (2)	1.177 (2.611)	.809 (1.042)	.006 (.000)	.291 (.215)	.328 (.202)	-.234 (.072)
Decision-making by both (2)	.614 (1.934)	.495 (1.075)	.303 (.607)	.253 (.342)	.451 (.715)	.319 (.298)
Publication restriction imposed by partner	.050 (.007)	-.197 (.091)	-.191 (.124)	-.484 (.686)	-1.016 (2.712)	-.757 (1.254)
Partner's office in same city as university		.241 (.330)		.023 (.004)		.796 (2.266)
Collaboration with public research organization (as opposed to firm)		-.001 (.000)		-.181 (.225)		-.446 (.720)
Ph.D. candidate is former employee of partner		-.430 (.362)		.859 (2.417)		1.274 (1.300)
Prior relation between TU/e and partner		-.300 (.342)		**-.719*** **(2.728)**		**1.306**** **(5.372)**
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2=.099	R^2=.160	R^2=.045	R^2=.134	R^2:.058	R^2:.222

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. All columns are binary logit regressions. Note: (1) Baseline is relationship managed by university. (2) Baseline is decision-making by university.

For our second outcome variable, *academic publications* (Table 4.4, Columns 3 and 4), we found no significant relationships. Apparently, project management aspects do not affect the likelihood of Ph.D. candidates having their results published in academic journals.

Our third outcome variable considers whether the developed *knowledge is patented* (Table 4.4, Columns 5 and 6). We found that the likelihood of patents is: (a) positively related to the partner funding the project. Arguably, this might be because the partner sees more commercial potential in the project, or has more control of the scientific direction. This finding is in agreement with

Czarnitzki and Fier (2003), who found that if a project is funded by a firm, the likelihood of patents increases because of the focus on commercialization activities; (b) the likelihood of patents is negatively related to joint management; (c) the likelihood of patents is positively related to a publication restriction imposed by the collaborating partner. This result is expected since a publication restriction is usually aimed at ensuring outcomes meet the novelty requirement of the patent office. Interestingly, the restriction does not negatively affect the likelihood of publication. In the control variables, we see that patenting likelihood increases if the partner's office is situated in the same city as the university. When considering this result, however, we should bear in mind that our data was collected at TU/e, located in a city that is also home to Philips research and many other Philips offices that collaborate with this university. With over 54,000 patents, Philips is a very patent intensive company and this may affect our results. We also observed that the positive effect of funding by a partner and publication restriction still remain significant after adding control variables that show the robustness effect of these two independent variables. Furthermore, collaboration with a public research organization as opposed to a firm is less likely to result in patents than one with a firm, which is not surprising.

Our fourth and fifth outcome variables are whether the Ph.D. candidate – after successful completion of the project – *is offered a job by the university or the collaboration partner respectively* (Table 4.4, Columns 7 to 10). Interestingly, a job offer by a university is less likely if the partner was involved in managing the relationship, either alone or together with the university. Although we have no exact idea why this would be the case, we only know that it is not due to the candidate already having been employed by the partner, because we included that as a control variable and it remains insignificant. A job offer by the partner is not related to any project management aspects, yet, unexpectedly, it is negatively affected by prior relationship between the university and the partner.

Our sixth and final outcome variable is whether *the collaboration was followed up by a new one* (Table 4.4, Columns 11 and 12). Here we observed that such a follow-up is more likely if the partner funded the project. This result still remains significant after adding control variables showing the robustness effect of this independent variable. We also observed that this is more likely if the project was also preceded by other collaboration. Thus, we observe evidence of long 'chains' of subsequent collaborations indicative of long-term partnerships

4.4.2. How do supervisors affect collaboration success?

Table 4.5 shows our regression results of the effect of supervisors' characteristics on the six different success measurements.

Table 4.5, Columns 1 and 2 show that the *level of knowledge transfer*: (a) is negatively related to the level of university supervisor knowledge. Indeed, a supervisor with a high knowledge level may well be more interested in publications than in facilitating knowledge transfer; (b) is positively related to both supervisors having similar opinions as can be expected; and (c) is negatively related to supervisor replacement during the project, again, as can be expected. Knowledge transfer is also more likely if the Ph.D. candidate is a former employee of a partner; again, this effect most probably reflects the candidate's familiarity with the organizational context.

Table 4.5 Regression analysis of how different measurements of collaboration success (dependent variables) are impacted by supervisors' characteristics

	Level of knowledge transfer [1,2]		**Resulted in academic publication [3,4]**		**Knowledge was patented [5,6]**	
Level of university supervisor knowledge	**-.409** (4.066)**	**-.377* (2.765)**	.558 (2.656)	.220 (.307)	**-.585** (4.849)**	-.453 (2.159)
Level of partner supervisor knowledge	.239 (1.890)	.278 (2.207)	-.229 (.517)	-.194 (.293)	-.061 (.079)	-.157 (.419)
Level of university supervisor enthusiasm	**.443** (4.160)**	.380 (2.547)	-.375 (.933)	-.046 (.010)	**.556* (3.541)**	**.651* (3.342)**
Level of partner supervisor enthusiasm	-.032 (.026)	-.071 (.103)	-.322 (.844)	-.554 (1.620)	-.115 (.209)	-.118 (.152)
Similar opinions between both supervisors	**.388** (5.839)**	**.323* (3.694)**	-.012 (.002)	-.049 (.027)	.250 (1.417)	.254 (1.026)
Supervisor replacement	**-1.286** (9.711)**	**-1.183** (6.989)**	-.223 (.107)	-.618 (.661)	.542 (1.293)	.221 (.147)
Openness of university supervisor	.153 (.673)	.089 (.195)	.045 (.020)	.069 (.028)	.113 (.181)	.022 (.005)
Openness of partner supervisor	-.013 (.006)	.098 (.275)	-.174 (.276)	-.081 (.039)	.259 (1.222)	.143 (.279)
Academic position of daily university supervisor	.180 (1.053)	.146 (.546)	**-.798** (6.363)**	**-.840** (4.527)**	-.151 (.406)	-.240 (.684)
Academic degree of partner supervisor	.003 (.000)	.112 (.215)	**.837** (4.589)**	.637 (1.844)	**-.544* (3.663)**	-.471 (1.970)
Partner's office in same city as university		-.410 (1.528)		**-.978* (2.872)**		**.904** (4.106)**
Collaboration with public research organization (opposed to firm)		-.470 (1.901)		.796 (1.384)		-.632 (1.694)
Ph.D. candidate is former employee of partner		**.936* (3.293)**		.000 (.000)		.025 (.001)
Prior relation between TU/e and partner		-.296 (.519)		**1.221* (2.861)**		-.562 (1.100)
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2= .201	R^2= .251	R^2= .149	R^2= .290	R^2= .140	R^2= .248

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. Columns [1,2] are ordinal logit regressions. All other columns are binary logit regressions.

Table 4.5 – Continued

	Subsequent job offer from university [7,8]		**Subsequent job offer from partner [9,10]**		**Collaboration was followed up [11,12]**	
Level of university supervisor knowledge	-.059 (.049)	.063 (.045)	**-.617** (5.918)**	**-.534* (3.414)**	**.628** (4.589)**	.540 (2.295)
Level of partner supervisor knowledge	-.019 (.007)	-.109 (.199)	.293 (1.876)	.364 (2.416)	-.074 (.085)	.058 (.042)
Level of university supervisor enthusiasm	.241 (.633)	.145 (.196)	**.477* (2.997)**	.359 (1.376)	-.272 (.756)	-.170 (.195)
Level of partner supervisor enthusiasm	.202 (.588)	.205 (.489)	.240 (.995)	.222 (.670)	-.036 (.015)	-.318 (.686)
Similar opinions between both supervisors	-.046 (.051)	-.045 (.042)	-.094 (.239)	.005 (.001)	.178 (.485)	.173 (.314)
Supervisor replacement	-.008 (.000)	.075 (.018)	-.525 (1.119)	-.548 (.903)	.205 (.117)	.220 (.090)
Openness of university supervisor	-.166 (.457)	-.179 (.467)	.070 (.095)	.234 (.857)	-.295 (.895)	-.540 (1.767)
Openness of partner supervisor	.077 (.107)	-.007 (.001)	-.045 (.044)	-.108 (.203)	-.258 (.841)	-.359 (.978)
Academic position of daily university supervisor	.236 (1.034)	.103 (.159)	-.296 (1.841)	-.305 (1.508)	.408 (1.863)	.371 (1.012)
Academic degree of partner supervisor	-.277 (.900)	-.148 (.223)	-.205 (.581)	-.100 (.111)	.522 (2.227)	**.818* (3.639)**
Partner's office in same city as university		.162 (.148)		.125 (.092)		.616 (1.134)
Collaboration with public research organization (opposed to firm)		-.109 (.059)		.104 (.060)		**-1.000* (2.891)**
Ph.D. candidate is former employee of partner		-.473 (.438)		**1.041* (2.835)**		19.959 (.000)
Prior relation between TU/e and partner		-.044 (.007)		-.540 (1.168)		.938 (1.938)
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2= .036	R^2= .052	R^2= .122	R^2= .189	R^2= .117	R^2= .332

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. All columns are binary logit regressions.

Regarding having an *academic publication* as outcome of a collaborative Ph.D. project (Table 4.5, Columns 3 and 4), we found that the likelihood of academic publications is negatively related to the university professor's academic position. University supervisors with a higher academic position are likely to have more managerial responsibilities as well as fewer incentives to publish compared to less senior colleagues. Consequently, the probability of publication might decrease. By adding control variables, the publication probability decreases if the partner's office is located in the same city as the university, which is unexpected. Prior relations between university and partners – indicative of trust between partners – increase the likelihood of academic publications.

Based on our third outcome variable, whether the *developed knowledge is patented* (Table 4.5, Columns 5 and 6), we found that patenting is supported by a university supervisor enthusiasm. In terms of control variables, co-location in Eindhoven increases the likelihood of patents. Note again that this effect is likely to be, at least partially, the result of collaborations with the Philips research in Eindhoven, which is very productive in terms of patenting.

For our fourth outcome variable, *job offer to Ph.D. from university* (Table 4.5, Columns 7 and 8), we found no significant relationships. None of the supervisor characteristics affects the likelihood of the Ph.D. being offered a job by the university after successful completion of the project.

For the fifth outcome variable (Table 4.5, Columns 9 and 10), we found that *a job offer by partner* is less likely when the university supervisor is very knowledgeable. This may be because a knowledgeable university supervisor is likely to be more research-oriented and the partner focuses more on the commercialization aspects of knowledge. As expected, we also observe that it is more likely if the Ph.D. candidate is a former employee of the partner.

Finally, for the sixth outcome variable, whether *the collaboration was followed up by a new one* (Table 4.5, Columns

11 and 12), we found that such a follow-up is more likely if the partner supervisor's has a high academic degree, possibly cognitive proximity can facilitate new collaboration. Moreover, follow-up collaboration is less likely if the original collaboration is with a public research organization than with a firm.

4.4.3. How does communication affect collaboration success?

The regression results on how different measurements of collaboration success are influenced by communication are shown in Table 4.6.

Regarding *the level of knowledge transfer* (Table 4.6, Columns 1 and 2), we found: (a) it is positively related to the frequency of meetings between the Ph.D. candidate and partner supervisor. As the Ph.D. candidate has a role of knowledge transfer between university and industry (Thune, 2009), the frequency of meetings between Ph.D. candidates and their supervisor at the partner provides the conditions to facilitate transfer of knowledge through discussion, brain storming, etc.; (b) the level of knowledge transfer is positively related to the quality of communication between the Ph.D. candidate and collaborating partner. This result remains significant after adding control variables that show the robustness effect of this independent variable while the effect of frequency of meetings between Ph.D. candidate and partner supervisor disappears. Besides, we observed that a high level of knowledge transfer is less likely if collaboration is with a public research organization as opposed to a firm. Moreover, it is more likely if the Ph.D. candidate is a former employee of the partner.

Regarding the second outcome, *academic publications* (Table 4.6, columns 3 and 4), we find no significant relationships.

For our third and fourth outcome variables, *patent and offering job to Ph.D. from university* (Table 4.6, Columns 5 to 8), we found no significant relationships. We do observe that if the collaborating partner's office is in Eindhoven, a patent is more likely. Moreover, collaboration with a public research organization compared to a firm reduces the likelihood of patents.

Table 4.6 Regression analysis of how different measurements of collaboration success (dependent variables) are impacted by communication characteristics

	Level of knowledge transfer [1,2]		**Resulted in academic publication [3,4]**		**Knowledge was patented [5,6]**	
Meeting frequency of Ph.D. candidate and university supervisor	-.078 (.545)	-.050 (.198)	-.105 (.335)	-.024 (.013)	-.021 (.026)	-.014 (.009)
Meeting frequency of Ph.D. and partner supervisor	**.184** (4.169)**	.104 (1.002)	-.075 (.217)	.017 (.008)	.066 (.347)	.158 (1.227)
Meeting frequency of both supervisors	.093 (.666)	.185 (2.074)	**-.444* (3.855)**	-.362 (2.042)	-.021 (.021)	-.073 (.171)
Quality of communications between Ph.D. and university supervisor	.107 (.400)	-.064 (.124)	.109 (.120)	.049 (.021)	.199 (.838)	.325 (1.738)
Quality of communications between Ph.D. and partner supervisor	**.299** (5.113)**	**.296** (3.999)**	-.098 (.124)	-.055 (.036)	.042 (.065)	-.209 (1.112)
Partner's office in same city as university		-.412 (1.758)		-.758 (2.150)		**.876** (4.545)**
Collaboration with public research organization (opposed to firm)		**-.721** (5.523)**		.904 (2.518)		**-1.215** (7.411)**
Ph.D. candidate is former employee of partner		**1.032** (4.627)**		.266 (.097)		.097 (.021)
Prior relation between TU/e and partner		-.192 (.264)		.934 (2.284)		-.696 (2.040)
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2= .119	R^2= .199	R^2= .088	R^2= .205	R^2= .013	R^2= .202

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. Columns [1,2] are ordinal logit regressions; all other columns are binary logit regressions.

Table 4.6 – Continued

	Subsequent job offer from university [7,8]		**Subsequent job offer from partner [9,10]**		**Collaboration was followed up [11,12]**	
Meeting frequency of Ph.D. candidate and university supervisor	.151 1.125	.121 (.648)	.073 .325	-.058 (.146)	**-.315**** **(4.040)**	-.248 (1.813)
Meeting frequency of Ph.D. and partner supervisor	036 .089	-.147 (1.136)	**.306**** **7.225**	**.497**** **(11.570)**	-.142 (1.143)	-.184 (1.253)
Meeting frequency of both supervisors	.078 .250	-.006 (.001)	.157 1.227	.124 (.556)	**.380**** **(4.760)**	**.488**** **(4.871)**
Quality of communications between Ph.D. and university supervisor	-.132 .330	-.152 (.388)	.249 1.332	**.448*** **(3.175)**	.074 (.091)	.027 (.008)
Quality of communications between Ph.D. and partner supervisor	.221 1.515	.320 (2.582)	.018 .011	-.070 (.109)	-.171 (.735)	-.406 (2.368)
Partner's office in same city as university		.260 (.415)		.046 (.013)		.702 (1.704)
Collaboration with public research organization (opposed to firm)		.007 (.000)		-.189 (.231)		-.652 (1.597)
Ph.D. candidate is former employee of partner		-.609 (.768)		**1.056*** **(3.114)**		**2.138*** **(2.994)**
Prior relation between TU/e and partner		-.196 (.158)		**-.924**** **(3.864)**		**.972*** **(3.092)**
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2= .024	R^2= .073	R^2= .130	R^2= .261	R^2= .074	R^2= .260

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. All columns are binary logit regressions.

For our fifth outcome variable (Table 4.6, Columns 9 and 10) we found that *offering job to Ph.D. from partner* is: (a) positively related to the high frequency of meetings between Ph.D. and partner supervisor; (b) positively related to the quality of communication between Ph.D. candidate and university supervisor. After graduation, the Ph.D. candidate is considered the main channel of knowledge transfer to the collaborating partner and tacit knowledge can be absorbed from this channel (Mangematin, 2000). Moreover, close and frequent relationships play an important role in obtaining tacit knowledge (Cavusgil *et al*., 2003) and inspire the collaborating partner to hire a Ph.D. candidate after graduation. Regarding the control variables, we observe again that the Ph.D. candidate is more likely to receive a job offer from a partner if the candidate is a former employee and less likely if the university already collaborated with the partner in question.

For the last outcome variable, *following-up of collaboration by a new one* (Table 4.6, Columns 11 and 12), we found that a high frequency of meetings between both supervisors more often results into a follow-up collaboration. Arguably, this indicates that both sides find each other helpful in solving other problems, which could lead to new collaboration. By adding control variables, we observed that such a follow-up is more likely if the Ph.D. candidate is a former employee of the partner and both partners have a prior mutual relationship. These results show the importance of social proximity in generating the trust and commitment, which in turn inspire to continue collaboration.

4.4.4. An integrated model

The regression analyses we presented so far on the effect of project management, supervision and communication on project performance, suffer from two limitations. First, each of the analyses assesses the effect of only one set of governance characteristics (project management, supervision, and communication). To assess the robustness of the results of the three separate regressions concerning these three characteristics, an additional analysis is required using a full model including all variables. Indeed, the results may change if the management, supervision and communication variables are inter-related in such a way that their joint inclusion would render some effects insignificant. Yet, given the number of observations (N=191), we were compelled to reduce the number of independent variables for such a combined analysis. A second limitation is that some variables, both dependent and independent, are based on the subjective assessment of the Ph.D. candidate in question. Hence, some findings may be based on unobservable individual characteristics (such as ability or personality) and could affect both their engagement in the Ph.D. as measured by governance variables and the performance outcomes of the Ph.D. project. We aimed to tackle both issues, albeit partially, by constructing an integrated model including project management, supervision and communication variables but excluding those variables most likely to suffer from individual candidate bias. We constructed an integrated model including all independent variables from the three separate analyses, but excluding the independent variables related to decision-making, levels of enthusiasm, similarity of opinions, openness and quality of communication. We also excluded the variable supervisor replacement because this is not just governance characteristic but can also be regarded as a performance indicator. Entering the remaining independent variables in a single model may raise new multicollinearity issues between these variables. With VIF values between 1.055 and 1.638, however, we can safely conclude that the integrated model does not suffer from multicollinearity.

Table 4.7 presents the regression results of the integrated model. This model includes 11 independent variables plus control variables. By comparing the results of the three separate regressions (Tables 4.4-4.6), we found that the significant results in the three previous analyses, remain significant except for three variables. Concerning funding by partner, its positive effect on follow-up collaboration found in Table 4.4, is still positive but insignificant in Table 4.7. For what regards the knowledge level of the university supervisor in Table 4.5, we no longer find any significant effect in Table 4.7. And finally, the positive effect of a high academic degree of the partner's supervisor on follow-up collaboration in Table 4.5 is no longer significant in Table 4.7.

Looking at the control variables in the integrated model, we recognize the effects observed before. Co-location in Eindhoven is associated with more patents indicative of a Philips effect. Interestingly, geographical proximity also favours follow-up collaboration suggesting that the Eindhoven region is supportive of long-term relationships. If we look at the difference between collaboration with a Public Research Organizations versus a firm, we find that knowledge is more easily transferred to a Public Research Organization than to a firm, indicative of the benefits of institutional proximity. However, the negative effect of collaboration with a public research organization on patenting in Tables 4.4 and 4.6, becomes positive in Table 4.7. That is, patenting is more likely if a Public Research Organization rather than a firm is the partner. A Ph.D. candidate who previously worked as an employee for the partner, i.e. who is socially proximate to the partner, is better able to transfer knowledge and more likely to get a job offer from the partner after the project. Finally, we find no effect of prior relationships between the university and the partner.

Hence, we conclude that, based on the full model, the main conclusions of the separate analyses remain intact.

Table 4.7 Integrated model

	Level of knowledge transfer [1,2]		**Resulted in academic publication [3,4]**		**Knowledge was patented [5,6]**	
Funding funded by partner	-.087 (.093)	-.485 (2.275)	-.036 (.004)	-.009 (.000)	**.955** (5.457)**	**1.335*** (6.996)**
Relationship managed by partner (1)	-.479 (1.278)	-.609 (1.872)	.901 (1.146)	1.090 (1.342)	-.612 (1.023)	-1.039 (2.265)
Relationship managed by both (1)	.327 (.900)	.366 (.964)	.692 (1.138)	.994 (2.000)	-.526 (1.229)	**-1.099** (3.995)**
Level of university supervisor knowledge	.154 (.729)	.087 (.190)	.483 (2.085)	.233 (.383)	**-.404* (2.772)**	-.186 (.406)
Level of partner supervisor knowledge	-.056 (.126)	-.055 (.174)	-.122 (.166)	-.151 (.188)	**.428** (4.045)**	.358 (2.091)
Academic position of daily university supervisor	.089 (.266)	132 (.484)	**-.717** (4.685)**	**-.750* (3.676)**	-.107 (.200)	-.073 (.066)
Academic degree of partner supervisor	.149 (.471)	.256 (1.195)	**.967** (5.667)**	.778 (2.414)	**-.906*** (8.817)**	**-.922** (6.437)**
Meeting frequency of Ph.D. candidate and university supervisor	-.123 (1.394)	-.119 (1.109)	-.059 (.082)	.082 (.129)	.050 (.119)	.091 (.288)
Meeting frequency of Ph.D. and partner supervisor	**.250*** (7.122)**	.148 (1.928)	-.173 (.862)	-.220 (.980)	.080 (.392)	.140 (.808)
Meeting frequency of both supervisors	.130 (1.215)	**.259* (3.708)**	**-.641** (5.733)**	-.490 (2.635)	-.013 (.007)	-.115 (.334)
Publication restriction imposed by partner	**.968** (4.596)**	**1.087** (5.057)**	-.376 (.259)	.118 (.021)	**1.325** (5.905)**	**1.353** (4.991)**
Partner's office in same city as university		-.467 (2.102)		-.557 (.960)		**1.148** (5.763)**
Collaboration with public research organization (as opposed to firm)		**.590* (3.097)**		-.976 (2.189)		**1.007* (3.772)**
Ph.D. candidate is former employee of partner		**1.403*** (8.369)**		-.013 (.000)		.188 (.068)
Prior relation between TU/e and partner		-.205 (.281)		.987 (1.882)		-.3000 (.304)
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2= .144	R^2= .244	R^2= .226	R^2= .310	R^2= .194	R^2= .346

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. Columns [1,2] are ordinal logit regressions; all others are binary logit regressions. Note: (1) Baseline is relationship managed by university.

Table 4.7 – Continued

	Subsequent job offer from university [7,8]		**Subsequent job offer from partner [9,10]**		**Collaboration was followed up [11,12]**	
Funding funded by partner	-.310 (.639)	-.412 (.919)	.504 (1.979)	.462 (1.191)	**.836* (3.419)**	.802 (2.042)
Relationship managed by partner (1)	**-2.132*** (8.036)**	**-2.306*** (8.704)**	-.252 (.215)	-.121 (.043)	-.322 (.223)	-.567 (.497)
Relationship managed by both (1)	**-.948** (3.948)**	**-.973* (3.508)**	.078 (.034)	-.084 (.032)	.203 (.131)	.296 (.183)
Level of university supervisor knowledge	-.056 (.049)	-.121 (.187)	-.104 (.225)	.193 (.574)	.175 (.429)	-.019 (.003)
Level of partner supervisor knowledge	-.133 (.399)	-.181 (.618)	-.059 (.085)	-.124 (.296)	.233 (1.050)	**.553* (3.657)**
Academic position of daily university supervisor	.347 (2.064)	.151 (.328)	**-.368* (2.780)**	-.347 (1.955)	.378 (1.672)	.248 (.543)
Academic degree of partner supervisor	-.242 (.682)	-.144 (.211)	-.193 (.517)	-.123 (.167)	.317 (.925)	.537 (1.697)
Meeting frequency of Ph.D. candidate and university supervisor	-.028 (.036)	-.042 (.069)	.145 (1.193)	.030 (.038)	**-.353** (4.579)**	-.241 (1.449)
Meeting frequency of Ph.D. and partner supervisor	.142 (1.187)	.071 (.223)	**.334*** (7.934)**	**.502*** (11.918)**	-.207 (2.093)	**-.355* (3.537)**
Meeting frequency of both supervisors	.099 (.353)	.034 (.034)	.123 (.667)	.076 (.187)	**.436** (5.214)**	**.494** (4.302)**
Publication restriction imposed by partner	.026 (.002)	-.176 (.073)	-.383 (.469)	-.599 (.933)	-.809 (1.540)	-.577 (.634)
Partner's office in same city as university		.155 (.129)		.031 (.006)		**1.002* (2.976)**
Collaboration with public research organization (as opposed to firm)		-.103 (.051)		.233 (.293)		.836 (1.715)
Ph.D. candidate is former employee of partner		-.389 (.287)		**1.155* (3.316)**		1.795 (2.122)
Prior relation between TU/e and partner		-.141 (.070)		-.764 (2.505)		.948 (2.510)
Department dummies	NO	YES	NO	YES	NO	YES
Model fit (Nagelkerke R^2)	R^2= .131	R^2= .173	R^2= .160	R^2= .261	R^2= .164	R^2= .336

* 10% significance level; ** 5% significance level; *** 1% significance level. All cells with 10% significance or better are shown in bold. All columns are binary logit regressions. Note: (1) Baseline is relationship managed by university.

4.5. Conclusions, managerial implications and future research

In this paper we focused on how choices regarding the governance and management of collaborative Ph.D. projects impact on their success. Despite Ph.D. projects being a common form of implementing university-industry collaboration, the extant literature has rarely focused on such collaborations (Perkmann *et al*., 2013). The results have implications for our understanding of the governance of collaborative Ph.D. projects and its effect on collaboration success.

This paper proposed a scale including several success measurements for collaborative Ph.D. projects. That is, in contrast to the existing literature, success is considered a multi-dimensional construct. Using this framework as the basis of our empirical study, this study has several implications for both university and industry, enabling partners to manage and govern collaborative Ph.D. projects successfully. In this study we first offered three models, each illustrating the effect of governance characteristics and the separate effect on the various success measurements. To check the robustness of our results, we constructed a single model containing all the factors with the least endogeneity. This model also confirms most of the significant results acquired from the three separate models.

We will briefly highlight the most important implications. In order to promote collaboration success, we advise partners to implement joint decision-making on the content of the project. Involving all partners in this decision-making process increases the synergy between them. Regarding the source of project funding, our findings suggest that success is highest if the partner funds the project. Interestingly, publication restriction does not only help patenting as one may expect, but it also renders knowledge transfer more effective. The level of the university supervisor's enthusiasm also supports patenting, which suggests that university partners should look for truly committed university personnel when entering a collaborative project.

Replacing a supervisor is a challenging issue for every partner during a project, and should be avoided whenever possible. Furthermore, we advise the collaborating partner to oversee the frequency and quality of communication with the Ph.D. candidate during the project. Finally, in line with findings in other studies on collaboration in other fields, previous collaboration experience between the two partners helps to achieve a higher level of success (Hahn *et al.,* 2008). Hence, aiming at long-term partnerships rather than one-off projects is likely to pay off.

Our study has several limitations that could encourage researchers to engage in future work on the governance of collaborative Ph.D. projects. One obvious limitation holds that we only studied Eindhoven University of Technology. As a technical university with close historical links to local industry, results may be to some extent specific to this regional context of Eindhoven.

We think more empirical studies are needed to examine the governance effect on the success of collaborations in other technical universities, as well as other types of universities, to better validate the proposed governance model. Finding out how the collaborative Ph.D. projects are managed in other types of universities and conducting a comparative study among different universities, are just two interesting avenues for future research. Another limitation of this study is that it only considers Ph.D. projects that have resulted in a published Ph.D. thesis (i.e. a successful defence). While such projects achieve diverse scores with our collaboration success measurements, we have not included projects that, for whatever reason, were aborted during their execution. Although such data is much harder to collect, it might provide new insights into collaborative Ph.D. projects. Moreover, it would be ideal to measure collaboration success from all the partners' perspectives (university, Ph.D. candidate and collaborating partner). However, gathering sufficient data for statistical analysis is problematic. As such, we suggest conducting case studies to compare the three perspectives. Finally, studies on the differences between governing non-collaborative and collaborative Ph.D. projects in order to achieve successful collaboration should be considered for future research.

4.6. Appendix

Table A: Description of dependent variables

Success measurements	Reference question in the questionnaire
Level of knowledge transfer to collaborating partner	Please indicate the extent to which the knowledge you developed in your Ph.D. thesis has been taken up by the collaborating partner. Please select the highest appropriate item in this progressive scale. - Not transferred at all - Transferred the knowledge (is now effectively available to its staff working in this field, for instance in the library, or has been presented to the staff) - Absorbed the knowledge (i.e. its researchers have studied and now master this knowledge) - Applied the knowledge in a business context - Commercialized the knowledge as a (smaller) element of a product or process - Commercialized the knowledge as the main basis or element or of a product or process
Resulted in academic publication	Did your Ph.D. project result in scholarly publications in academic journals? - No - Yes
Knowledge was patented	Did your Ph.D. project result in a patent or patent application with you as a listed inventor? - No - Yes
Subsequent job offer from university	After your Ph.D. project was finalized, did the university offer you a position? - No - Yes
Subsequent job offer from collaborating partner	After your Ph.D. project was finalized, did the collaborating partner offer you a position? - No - Yes
Collaboration was followed up	After your Ph.D. project was finalized, did the university and the collaborating partner get engaged in a new collaboration? - No - Yes

Table B: Description of independent variables

Governance characteristics	Name of variable	Reference question in the questionnaire
Project management	Ph.D. project funder	Who funded your Ph.D. project? - The collaborating partner (either by direct employment or by a contract to the university) - Others (e.g. the university own funds, a funding organization)
	Prominent partner in managing the coordination	Which organization was most prominent in managing the coordination or relationship? - The university - The collaborating partner - Both to the same degree
	Type of decision-making between both partners	How was the decision-making in the project best characterized? - Mostly done by university - Mostly done by the collaborating partner - Joint decision-making with an equal involvement of both partners
	Publication was prohibited due to the collaborating partner's restrictions	Were there research results that could not be published because the collaborating partner wished to keep these confidential? - No - Yes
Supervision	Academic position of the university daily supervisor	What was the position of your university daily supervisor when you started your Ph.D. project? - Assistant professor - Associate professor - professor
	Academic degree of the collaborating partner supervisor	Scientific degree of your (main) supervisor at the collaborating partner when you started your project. - Bachelor or Master - Ph.D. - Professor
	Level of university supervisor's knowledge in Ph.D. topic	How would you rate the knowledge of your university supervisor(s) in the specific topic of your Ph.D. study? (Scale: Very low to very high)
	Level of collaborating partner supervisor's	How would you rate the knowledge of your supervisor(s) at the collaborating

	knowledge in Ph.D. topic	partner in the specific topic of your Ph.D. study? (Scale: Very low to very high)
	Level of university supervisor's enthusiasm in Ph.D. topic	How would you rate the enthusiasm/personal involvement of your university supervisor(s) in the specific topic of your Ph.D. study? (Scale: Very low to very high)
	Level of collaborating partner supervisor's enthusiasm in Ph.D. topic	How would you rate the enthusiasm/personal involvement of your supervisor(s) at the collaborating partner in the specific topic of your Ph.D. study? (Scale: Very low to very high)
	Similar opinion between university and collaborating partner supervisors on Ph.D. topic	To what degree did the supervisor(s) at university and those at the collaborating partner usually agree (or have similar opinions) about choices concerning the project? (Scale: Very low to very high)
	Replacing any of the supervisors during the Ph.D. project	Were any of your supervisors replaced during the course of your Ph.D. project? - No - Yes
	Openness of university supervisor to any idea	To what degree was your university supervisor(s) open to any idea or change in the project? (Scale: Very low to very high)
	Openness of collaborating partner supervisor to any idea	To what degree was your supervisor(s) at the collaborating partner open to any idea or change in the project? (Scale: Very low to very high)
Communication	Meeting frequency of Ph.D. candidate and university supervisor	Please indicate the average frequency of supervision meetings you had with (any of) your university supervisors. (Note: this is about supervision meetings, not about other events at which you met these persons) - More than once a week - About every week - About every two weeks - About every month - About every 3 months - About every 6 months

		- Less than every 6 months
	Meeting frequency of Ph.D. candidate and collaborating partner supervisor	Please indicate the average frequency of supervision meetings you had with (any of) the supervisors at the collaborating partner (Note: this is about supervision meetings, not about other events at which you met these persons) - More than once a week - About every week - About every two weeks - About every month - About every 3 months - About every 6 months - Less than every 6 months
	Meeting frequency of both supervisors	What was the frequency of meetings where both the supervisors of the university and the supervisors at the collaborating partner were present? - About every month - About every 3 months - About every 6 months - About every year - Less than every year
	Quality of communication between Ph.D. candidate and university supervisor	How would you rate the quality of communication between you and your university supervisor(s)? (Scale: Very low to very high)
	Quality of communication between Ph.D. candidate and collaborating partner supervisor	How would you rate the quality of communication between you and your supervisor(s) at collaborating partner? (Scale: Very low to very high)

Table C: Description of control variables

Control Variables	Reference question in the questionnaire
Partner's office in same city as university	Indicate name of city and country of the offices of the collaborating partner where your supervisor was located:
Collaboration with research institute (opposed to firm)	Your Ph.D. project was a collaboration between Eindhoven University of Technology and … - A firm - A research institute
Ph.D. candidate is former employee of partner	Were you a former employee of the collaborating partner before your Ph.D. project? - No - Yes
Prior relationship between TU/e and collaborating partner	Prior to your Ph.D. project, have the supervisors from the university and from the collaborating partner worked together (e.g. research, projects or collaborations)? - No - Yes - Don't know
Differences between the various disciplinary departments at the university	In which university department did you conduct your Ph.D. project? - Applied Physics - Biomedical Engineering - Architectural Science - Chemical Engineering - Electrical Engineering - Industrial Design - Industrial Engineering and Innovation Sciences - Mathematics and Computer Sciences - Mechanical Engineering

Table D: Correlation between independent and control variables

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Funding funded by partner (1)																			
Relationship managed by partner (2)	.035																		
Relationship managed by university (3)	-.174#	-.461§																	
Relationship managed by both (4)	.154#	-.358§	-.664§																
Decision-making by partner (5)	.050	.585§	-.453§	-.017															
Decision-making by university (6)	-.171#	-.354§	.487§	-.213§	-.477§														
Decision-making by both (7)	.140*	-.116	-.138*	-.667§	-.336§	-.667§													
Publication restriction imposed by partner (8)	.112	-.078	.009	.057	-.030	-.149#	.185#												
Level of university supervisor knowledge (9)	-.164#	-.046	.178#	-.149#	-.152#	.194§	-.079	-.112											
Level of partner supervisor knowledge (10)	-.057	.107	-.135*	.050	.178#	-.049	-.100	-.159#	.329§										
Level of university supervisor enthusiasm (11)	.006	-.031	.115	-.094	-.124*	.072	.028	.022	.518§	.091									
Level of partner supervisor enthusiasm (12)	.080	.242§	-.206§	.010	.152#	-.138*	.017	.001	.234§	.481§	.290§								
Similar opinions between both supervisors (13)	.123	.161#	-.041	-.096	.000	-.020	.022	-.084	.231§	.292§	.266§	.469§							
Supervisor replacement (14)	.134*	.092	.063	-.145#	.064	.068	-0127*	-.149#	-.216§	-.050	-.211§	-.084	-.147#						
Openness of university supervisor (15)	.060	.157#	-.082	-.046	.127*	-.092	-.010	.037	.160#	.010	.223§	.138*	.320§	-.029					
Openness of partner supervisor (16)	.079	.082	-.043	-.024	-.065	.017	.037	-.071	.146#	.140*	.112	.406§	.464§	-.086	.469§				
Academic position of daily university supervisor (17)	.104	.139*	-.047	-.067	.057	-.122*	.082	.008	.058	-.025	.019	.006	.178#	-.096	.219§	.102			
Academic degree of partner supervisor (18)	.007	.052	.059	-.105	.078	-.012	-.054	-.044	.060	.285§	.086	.191§	.290§	-.011	.054	.155#	.172#		
Meeting frequency of Ph.D. candidate and university supervisor (19)	-.075	-.300§	.272§	-.034	-.412§	.318§	.008	.026	.228§	-.076	.367§	-.055	-.034	-.032	-.175#	-.018	-.069	.019	
Meeting frequency of Ph.D. and partner supervisor (20)	.058	.311§	-.453§	.241§	.474§	-.493§	.127*	.064	-.156#	.082	-.093	.176#	-.025	.003	-.059	-.114	.138*	.037	-.196§
Meeting frequency of both supervisors (21)	.091	.046	-.240§	.213§	.078	-.295§	.250§	.024	.019	.003	.040	.110	-.015	.005	-.160#	-.008	.026	-.013	.139#
Quality of communications between Ph.D. and University supervisor (22)	.011	-.104	.147#	-.067	-.148#	.049	.073	-.089	.412§	.131*	.634§	.197§	.222§	-.104	.274§	.144*	.034	.089	.311§
Quality of communications between Ph.D. and partner supervisor (23)	.059	.246§	-.270§	.075	.125*	-.215§	.123*	.067	.118	.301§	.174#	.544§	.378§	-.099	.203§	.448§	.101	.125*	-.064
Partner's office in same city as university (24)	-.051	-.057	-.022	.071	.035	.085	-.121*	-.091	-.049	-.027	-.090	-.105	-.093	.008	-.055	-.069	.123*	-.059	.064
Collaboration with research institute (opposed to firm) (25)	.047	-.145#	-.052	.176#	-.078	-.150#	.228§	.237§	-.202§	-.205§	.077	-.071	-.112	.021	.004	-.016	-.016	.231	.049
Dept of Applied Physics (26)	.033	.154#	-.061	-.165	.161#	-.085	-.046	-.106	.108	.094	-.011	.118	.125*	-.020	.057	.056	.094	.024	-.152#
Dept of Electrical Engineering (27)	.054	.001	-.078	.082	.085	-.130*	.067	.078	.068	.185#	.122*	.002	-.029	.034	.012	-.010	.033	-.011	.041
Dept of Mathematics and Computer sciences (28)	.020	.001	-0110	.115	.179#	-.162#	.022	.115	-.072	-.055	-.005	.050	-.016	.030	.033	.063	.075	-.025	.050
Dept of Mechanical Engineering (29)	.099	-.198§	.119	.041	-.228§	.067	.122*	.078	.057	-.057	.085	-.073	-.054	-.062	-.049	.008	-.053	-.105	.213§
Management or design department(30)	.005	.223§	-.091	-.092	.114	-.051	-.043	-.081	.029	-.084	.041	.108	-.014	-.055	.052	-.027	.166#	.028	-.114
Dept of Chemical Engineering (31)	-.171#	-0133*	.154#	-.050	-.215§	.262§	-.098	-.050	-.163#	-.068	-.183#	-.157#	-.011	.066	-.077	-.068	-.238§	.073	-.031
Ph.D. candidate is former employee of partner(32)	.135*	.109	-.118	.033	.159#	-.171#	.048	-.047	-.028	.023	.050	.204§	.195§	-.097	.134*	.085	.090	.017	-.097
Prior relationship between TU/e and collaborating partner(33)	-.080	.068	.056	-.116	.140*	-.016	-.104	-.112	.172#	.070	.021	.034	.094	.074	.191#	.124	.092	.140*	-.050

'*': p<0.10; '#': p <0.05; '§':p<0.01

1. Pearson was used to measure the correlation between continuous variables.
2. Phi coefficient was used to measure the association between dichotomous variables.
3. T-test was used to measure the association between dichotomous and continuous variables.

Table D – Continued

Variables	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)
Meeting frequency of Ph.D. and partner supervisor (20)														
Meeting frequency of both supervisors (21)	.469§													
Quality of communications between Ph.D. and University supervisor (22)	-.124*	.061												
Quality of communications between Ph.D. and partner supervisor (23)	.252#	.134#	.262§											
Partner's office in same city as university (24)	.005	.099	-.039	-.067										
Collaboration with research institute (opposed to firm) (25)	-.023	.088	.051	.091	.022									
Dept of Applied Physics (26)	.120*	-.159#	-.119	.007	-.202§	-.133*								
Dept of Electrical Engineering (27)	.038	.015	.153#	.227§	.033	.172#	-.177#							
Dept of Mathematics and Computer sciences (28)	.190§	.281§	-.032	.020	.106	.145#	-.156#	-.136*						
Dept of Mechanical Engineering (29)	-.097	.029	.093	-.130*	-.099	-.009	-.213§	-.185#	-.288§					
Management or design dept (30)	.183#	.034	.064	.041	-.011	-.031	-.181#	-.154#	-.136*	-.185*				
Depr of Chemical Engineering (31)	-.317§	-.120*	-.122*	-.113	.165#	-.084	-.283§	-.240§	-.212§	-.288§	-.246			
Ph.D. candidate is former employee of partner(32)	.103	-.010	.069	.116	.031	-.025	.042	.087	.065	-.056	.081	-.108#		
Prior relationship between TU/e and collaborating partner (33)	-.008	.141*	.136*	-.079	.150#	-.085	-.011	-.052	.029	.035	.067	-.054	-.037	

'*': p<0.10; '#': 'p <0.05; '§':p<0.01

1. Pearson was used to measure the correlation between continuous variables.
2. Phi coefficient was used to measure the association between dichotomous variables.
3. T-test was used to measure the association between dichotomous and continuous variables.

5. Does working with industry come at a price? A study of doctoral candidates' performance in collaborative vs. non-collaborative Ph.D. projects[1]

Abstract

University-industry collaboration in the form of Ph.D. projects is an interesting channel of knowledge transfer, which may facilitate effective knowledge transfer. But how do such projects compare with regular Ph.D. projects in terms of academic performance? The question holds whether there is a trade-off between working with industry and having academic impact. We investigate the performance differences between collaborative and regular Ph.D. projects in terms of the amount of scholarly output and in terms of the quality of scholarly output? Conducting an empirical study on 448 collaborative and non-collaborative Ph.D. projects successfully concluded at the Eindhoven University of Technology, we observe that doctoral researchers that conducted a collaborative Ph.D. project outperform their peers in academic performance, both in quality and quantity. The same holds – less surprising – for

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[1] This chapter is based on:
Salimi, N., Bekkers, R., Frenken, K. (2014). Does working with industry come at a price? A study of doctoral candidates' performance in collaborative vs. non-collaborative Ph.D. projects. Submitted to *Technovation* (now in the second round of review).
Earlier versions of this paper were presented at workshops at the University of Kassel (March 2014), Hitotsubashi University (May 2014) and Utrecht University (June 2014).

patenting, both in terms of number of patents and the impact of these patents. A deeper investigation of the determinants of this improved performance reveals that it depends strongly on the nature of the collaborative partner. The numerous collaborations in our data set with Philips, a company with a long research culture, displayed higher performance levels, as well as Ph.D. projects with Public Research Organisations. Collaborations with other firms, however, showed no significant performance differences with non-collaborative peers: they were not significantly better (but were not significantly worse either). We believe our study has policy implications, in that we see no reasons for universities to be reserved to enter into Ph.D. collaborations when such opportunities arise.

***Keywords*:** university-industry relations, technology transfer, collaborative and non-collaborative Ph.D. projects, performance, publication performance, patenting performance, citations, bibliometric data

5.1. Introduction

Firms increasingly rely on external knowledge as a source of competitive advantage. One effect of this tendency is the increased rate of university-industry collaborations. The results of academic research on innovation are especially important for science-based industries such as biotechnology and semiconductors (Ponds *et al.*, 2010), but are also valuable in many other areas of science and technology. At the same time, universities are motivated to develop closer relationships with firms in order to gain access to research funds and firms' resources. Additionally, universities are being increasingly expected to contribute to the local or regional economy in terms of innovativeness or employment (the 'third mission'), and there is political pressure on universities to do so (Geuna and Muscio, 2009).

There are different ways in which universities can transfer knowledge to industry, including contract research, collaborative research, patenting, and licensing (to see detailed discussion on different forms of knowledge transfer from universities to firms refer to Gilsing *et al.*, 2011). While much of the earlier research on university-industry relations has focused on channels such as patenting and the role of technology transfer offices/technology licensing offices, some recent papers plea for greater attention to more interactive or collaborative modes, sometimes referred to as 'academic engagement' (D'Este and Patel, 2007; Perkmann *et al.*, 2013). There are several reasons why firms are motivated to get involved in active collaborations: (1) in many knowledge areas, the tacit nature of knowledge necessitates actively working together with universities, (2) universities are major sources of databases and research facilities that would be too expensive for firms to construct in-house, and (3) through collaboration, firms can co-develop knowledge that is relevant to the specific problems they face (Liebeskind *et al.*, 1996, Ponds *et al.*, 2007). Furthermore, collaboration can improve partners' innovation capability and economic performance (Lööf and Broström, 2008) and provide access to resources, skills, data, and transfer of technology (Albors, 2002) as well as human capital (Lin and Bozeman, 2006).

In this study we consider one of the promising forms of collaboration between universities and industry, which is collaboration through Ph.D. projects. In fact, almost one third of all Ph.D. projects at Eindhoven University of Technology (the institute where we collected the data for this study) are collaborative projects, making it a much more common phenomenon than university patenting, for instance. While collaborative Ph.D. projects have great potential for the transfer of knowledge between university and industry, they have received very little attention in the existing literature on university–industry relations.

Apart from the alleged benefits, industry involvement may also harm academic research as corporate interest may come to dominate public interests (Washburn, 2005). One particular concern about entering into such collaborations is that their academic performance might not be at the same standard as regular, non-collaborative Ph.D. projects. The effect of collaboration with industry on the performance of research projects is not yet clear and the evidence of such effects is scarce (for a review, see Perkmann *et al*., 2013). On the one hand, involving industry in collaboration can shift research towards narrow corporate interests (Nelson, 2004). On the other hand, collaboration with industry may improve research outcomes if both partners have complementary knowledge and converging interests (i.e. Gulbrandsen and Smeby, 2005).

The aim of this paper is to investigate the effect of industry collaboration on academic performance in the context of Ph.D. projects. To do so, we conducted an empirical study on 448 collaborative and non-collaborative Ph.D. projects at Eindhoven University of Technology, looking at actual differences in performance levels, and identifying the determinants of performance differences. Our collaborative projects include not only projects with firms, but also projects with Public Research Organisations (PROs), allowing us to understand more about performance differences specifically related to working with firms (opposed to those associated with collaboration as such).

5.2. Literature review

Even though for many universities – if not most – patenting is much less common than collaboration, there is extensive literature on university patenting and its potential trade-offs. This literature especially focuses on the question to what extent university patenting has detrimental effects on the rate, quality and direction of academic publications. In the late 2000s, this stream of literature moved for a consensus that such a trade-off was not present. Azoulay *et al.* (2009) concluded that patenting has a positive effect on the rate of publications and a mildly positive effect on the quality of these publications. Looking at the field of nanotechnology, Meyer (2006) found that patenting scientists outperform their solely publishing (non-inventing) peers in terms of publication counts and citation frequency, but made the reservation that at the very top, inventor-authors appear not to be among the most highly cited authors in their category. Other studies also found robust complementarities between publishing and patenting (for a more extensive review, see Genua and Nesta, 2006).

Notwithstanding that the positive evidence, open issues remain regarding teaching quality, open science and fundamental long-term research. Along those lines, Baldini (2008) discussed issues such as: threats to scientific progress (disclosure and data sharing restrictions, the tragedy of the anti-commons, restrictions on research tools), changes in research (decline in patent quality, substitution between basic and applied research), threats to teaching activity (decline in teaching time, conflicts of interest, decline in student publications and informal learning) and threats to industry (restrictions on university-industry communications, delays to industry innovation, loss of proprietary information, obstacles to new research fields, unreasonable cost increases).

Compared to academic patenting, the literature on the (performance) effects of university-industry collaboration is much scarcer. One topic that has received attention in such collaborations is the disclosure of research output. Making research outcomes public is one of the most challenging issues between university and industry (Etzkowitz and Leydesdorff, 2000; Salimi *et al.,* 2014, Chapter 3). Indeed, universities are publication oriented and usually want to publish their research output as widely as possible. Furthermore, they have an incentive to publish their results quickly to increase their (citation) impact. However, industry aims to commercialise the knowledge. Hence, generally speaking, firms have an incentive to appropriate their knowledge through secrecy, patenting or otherwise, rather than to disclose it through academic publications (Partha and David, 1994). As a result, they may want to place restrictions on the disclosure of findings, or delay publication, so that they can apply for a patent (Blumenthal *et al*., 1996b, Salimi *et al.,* 2014, Chapter 3). Therefore, collaboration with industry may increase the secrecy of results (Blumenthal *et al.,* 1996a) and can cause delay in publications (Nelson, 2004). This seems to be in line with the findings of Lin and Bozeman (2006) that Ph.D. candidates having previous industry experience produce fewer publications over their entire career. However, Gulbrandsen and Smeby (2005) found a positive relationship between collaboration with industry and a high level of publications for Norwegian professors. Ponomariov and Boardman (2010) also found that faculties affiliated with a centre for industry collaboration were likely to have more publications than faculties not affiliated with such a place. Similarly, Abramo *et al.* (2009) found that university researchers who have collaboration with private sector have higher publications compared to their colleagues who are not involved in such collaboration. Among other things, such positive effects may be thanks to the exchange of complementary knowledge, as suggested by Banal-Estañol *et al.* (2011). Moreover, in collaborative projects, both partners can mutually benefit from each other's abilities in terms of specific (unique) skills and data as well as facilities and equipment - especially when we are talking of unique facilities that very few organisations can afford.

A second topic discussed in the literature is the effect of collaboration on the nature of research findings. There are concerns that such industry involvement shifts the researchers' agendas toward more applied topics rather than focusing on basic science (Perkmann *et al.,* 2013) and that collaboration moves research towards narrow corporate interests. This could lead to a lower relevance and impact of research. At the same time, collaborations might be a source of valuable for exploring and new ideas (Perkmann and Walsh, 2009), which can lead to a higher publication output and a higher impact. For instance, Lee (2000) found in a survey among U.S. faculty members and industry researchers that both experienced benefits for their own research programmes. And, more recently, Wright *et al.* (2014) looked at over 12,000 inventions from the University of California. They found that corporate-sponsored inventions are licensed and cited more often than federally sponsored ones, which do not seem to suggest that corporate sponsoring leads to more research topic.

Summing up, while the available literature does provide deep insight into the impact of patenting on publication performance, the insight on the impact of collaboration on publication is much more limited and rather inconclusive. Literature on such impact in the context of Ph.D. collaborations – which are quite common, as we explained – is not available, to the best of our knowledge. We only know of one other study that attempts to explain both the publication and patent output of former Ph.D. candidates (Buenstorf and Geissler, 2014). Different from our study, they did not look at university-industry collaboration, as they focused on the effect of the Ph.D. supervisor.

5.3. Data and methodology

In order to investigate the academic performance of doctoral candidates, and to compare those who collaborated with industry with those who did not, we collected bibliometric data for former doctoral candidates at Eindhoven University of Technology in the Netherlands. Our central unit of analysis was a doctoral candidate that had successfully completed a Ph.D. thesis, and we collected data concerning publications (including publication citation data) and patent data (including patent citation data), both for the time window between four years before the Ph.D. defence, up to seven years after the defence. We also collected a variety of other data to use as control variables.

Preferring to collect data at one single university in order to reduce the variance stemming from differences between universities (e.g. arising from variance in institutional arrangements and settings), we selected Eindhoven University of Technology because of its extensive track record collaborating with industry in technological research. The university is based in the 'Brainport' region, which hosts many high-tech firms including Philips (a diversified, high-tech multinational), ASML (the world's leading firm in lithography for computer chip production), FEI (a leading specialist in transmission and scanning electron and ion microscopy) and NXP (a large semiconductor manufacturer). The intensive collaboration with industry, also reflected in a significant number of Ph.D. collaborations, allowed us to construct a database of sufficient size to address our questions.

We investigated all 784 Ph.D. theses that were successfully defended at this university in the years 2000-2005. We included theses from all university departments being Applied Physics, Chemical Engineering and Chemistry, Electrical Engineering, Mathematics and Computer Science, Mechanical Engineering, as well as four departments involved in management and design. These are the departments of Built Environment, Biomedical Engineering, Industrial Design, and Industrial Engineering and Innovation Sciences. Because of the lower number of collaborations in these departments and the fact that they are more similar in nature (compared to the 'hard core' technical departments), we grouped these departments together in our analyses.

Based on the content of the summary and preface of these theses, we identified a total of 89 collaborate projects with firms. We also identified another 135 collaborations with Public Research Organisations (PROs), which we decided to analyse as well because they can inform us about performance differences specifically related to involving firms (e.g. possible effects of research being narrowed to corporate interests, or less complete disclosure) verses differences associated with collaboration as such. In our study we excluded, however, collaborative projects with government institutions and those with other universities, as we expected them to have different aspects than the collaborations we wished to focus on. In order to compare the 224 identified collaborative projects with regular, non-collaborative Ph.D. projects, we also selected 224 Ph.D. projects that were not the result of any collaboration. While our analytical methodology does not require a matched sample, we nevertheless did so in order to make descriptive statistics more informative. The matching was performed using the following criteria: university department, gender, nationality, and year of graduation (i.e. year of thesis defence).

For performance data relating to the doctoral candidates' published works, we restricted ourselves to publications in peer-reviewed journals. Following the findings of Kulkarni *et al.* (2009) on the coverage of peer-reviewed journals in various publication databases, we chose Elsevier's Scopus database as our main source, and cross-checked our results with other sources (including résumés by the candidates themselves) to avoid both type I and type II errors. We selected data on all papers in which the focal doctoral candidate was listed as author or co-author. To determine the quality (or: impact) of publications we relied on citation performance. An important decision here is whether self-citations are included or not. Some scholars believe that self-citations artificially inflate citations scores and the actual impact of papers (e.g. Glänzel, 2003). However, others hold the view that self-citation is a natural way for authors to strengthen their knowledge or idea (e.g. Hyland, 2003). We performed all our analyses both including and excluding self-citations, and in virtually all cases the outcomes were similar. Not taking position in this discussion, we measured citation performance both including and excluding self-citations.

For patent data, we used the Thomson Reuters Derwent Innovations Index (DII) / Derwent World Patents Index (DWPI) database. The significant advantages are that this database comprises patent family information (thus preventing double-counts) and that patent metadata has been cleaned up and harmonised. We counted all patent families for which the doctoral candidates were listed as one of the inventors.

For both the publication and the patent data, we restricted our search to those published (or patents applied for) during the four years preceding the graduation year – the typical length of a Ph.D. project in the Netherlands – and the seven years after the graduation year. As the doctoral candidates graduated between 2000 and 2005, our publication and patent observations span from 1996 to 2012. Our final dataset includes a total of 4447 scientific publications and 861 patents.

In sum, in the analysis below, the word 'publication' refers to a peer reviewed publication as registered in Scopus with the focal doctoral candidate as author (or co-author); 'patent' means a patent family (as defined in our DII database) with the doctoral candidate listed as an inventor; 'Ph.D. project' means a doctoral research project that was successfully defended by the candidate. Furthermore, by 'collaborative doctoral candidate' we refer to a researcher who was involved as a Ph.D. in a collaborative Ph.D. project with industry or with a PRO, and by 'non-collaborative doctoral candidate' we refer to a peer involved in a Ph.D. project which was not a collaboration at all.

5.3.1. Descriptive analysis

A first glimpse of our data is provided in Table 5.1, showing the descriptive statistics comparing collaborative and non-collaborative doctoral candidates and using the 'moving' time window of 4+7 years as defined in the previous section. We observe that doctoral candidates in collaborative projects have a higher average number of publications. This is true for both collaborations with firms as collaborations with PROs (which even score better). Collaborations also have a higher number of citations in total, but not per publication. Results are robust when including or excluding self-citations.

Table 5.1 Descriptive data concerning publication performance (from 4 years before to 7 years after graduation)

Groups	**Number of doctoral candidates**	**Number of publi-cations**	**Mean number of publications per candidate**	**Total number of citations** (incl. / excl. self-citations)	**Mean number of citations per candidate** (incl. / excl. self-citations)	**Mean number of citations per publication** (incl. / excl. self-citations)
Doctoral researchers in collaborative Ph.D. projects with firms	89	1105	12.42	11,274 / 9042	127 / 102	10.20 / 8.18
Doctoral researchers in collaborative Ph.D. projects with PROs	135	1554	11.51	18,849 / 14,603	140 / 108	12.13 / 9.40
Doctoral researchers not in collaborative Ph.D. projects	224	1788	7.98	25,005 / 18,856	112 / 84	13.98 / 10.55

Table 5.2 shows descriptive information on the patenting performance for the doctoral researchers in our data set. Perhaps less surprisingly, collaborative doctoral candidates are more often listed as inventors on patents and receive more citations than their non-collaborative peers, both in total and per patent.

Table 5.2 Descriptive data concerning patenting performance (from 4 years before to 7 years after graduation)

Groups	**Number of doctoral candidates**	**Number of patents**	**Mean number of patents per candidate**	**Total number of citations**	**Mean number of citations per candidate**	**Mean number of citations per patent**
Doctoral researchers in collaborative Ph.D. projects with firms	89	337	3.79	940	10.56	2.80
Doctoral researchers in collaborative Ph.D. projects with PROs	135	343	2.54	426	3.16	1.24
Doctoral researchers not in collaborative Ph.D. projects	224	181	0.80	197	0.88	1.09

5.4. Main findings and discussion

Looking closer at our central research question, Section 5.4.1 starts by examining the relationship between the quantitative and qualitative performance of projects, including the question of whether there are trade-offs. Then Section 5.4.2 considers whether particular time patterns affect our findings on performance differences between the collaborative and non-collaborative doctoral candidates. In Section 5.4.3, we present a more detailed investigation, where we distinguish not only between different types of collaboration, but also consider alternative explanations in an attempt to understand what actually causes performance differences. This final analysis is based on a series of regression analyses.

5.4.1. Publication and patent performance

The descriptive overview data provided earlier in this chapter aggregates the data of all cases, and reports on averages. One question that arose is whether there are trade-offs in terms of quantity (number of publications) and quality (here represented by citation impact), and whether these are different for candidates involved in collaborative versus non-collaborative Ph.D. projects. To analyse this, we plotted these two dimensions for all the individual candidates (Figure 5.1). While the non-collaborative candidates strongly cluster in the lower left of the plot (few publications and low citation score), the collaborative candidates often do better in both dimensions. As such, our data does not suggest any of the above-mentioned types of trade-offs; also at individual candidate level, collaborative candidates combine higher publication performance and higher publication impact. We performed a similar analysis excluding self-citations (not shown) and still found similar results.

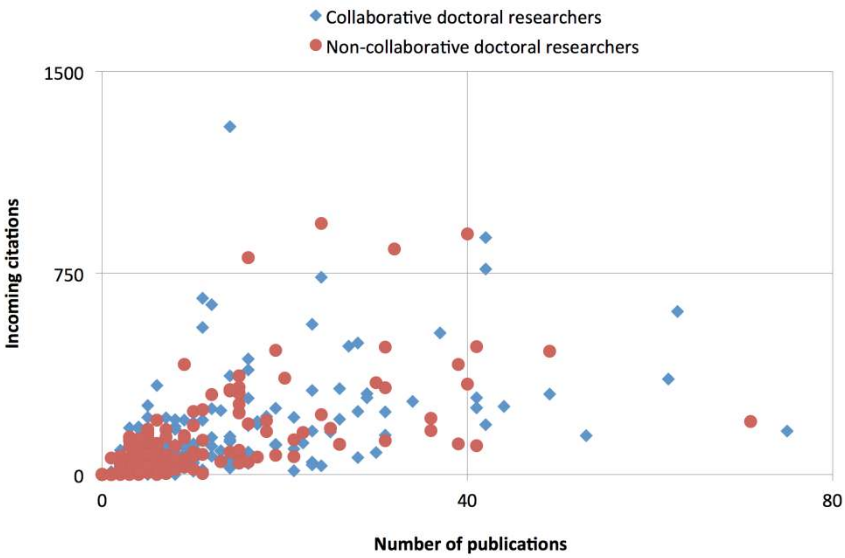

Figure 5.1 Publications and forward citations per project (including self-citations)

We performed a similar analysis with patent performance, again considering the individual project level. The results are shown in Figure 5.2. This data is more discrete in nature. As evidenced by Table 5.2, we have considerably fewer patent observations than publication observations - and many (often non-collaborative) projects overlap at the [0,0] coordinate of this graph. Nevertheless, we see a similar pattern as with publications: at individual level, collaborative doctoral candidates often combine a high performance in both dimensions.

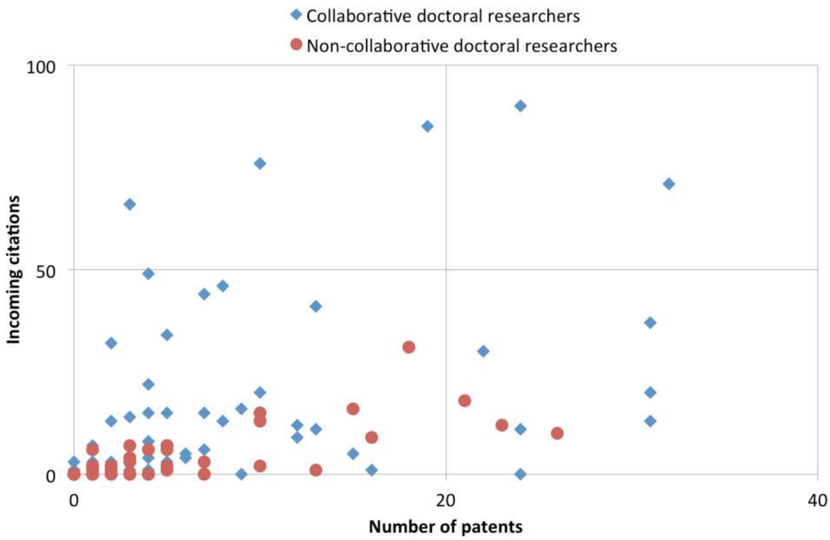

Figure 5.2 Patents and forward patent citations per project

5.4.2. Time profiles in publication and patent performance

As mentioned earlier, we focussed on Ph.D. projects that were finalised between the year 2000 and 2005, and we collected all associated publication and patent data for the Ph.D. candidates involved in the time frame 1996-2012. Using the time dimension in our data we can look at specific timing differences between collaborative and non-collaborative doctoral candidates. Do some result in early performance, while others only bear fruit in the longer term? Arguably, collaborative doctoral candidates are more likely to move to industry, and may consequently produce fewer publications than their counterparts who stayed in academia and used a postdoc period to get more papers out of their thesis research. Moreover, students aiming to stay in academia (read: mostly students on non-collaborative projects) might have stronger incentives to publish, as this is a key ticket for a career at a university.

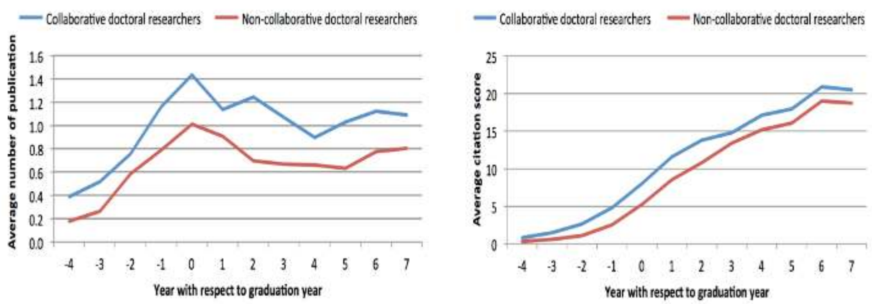

Figure 5.3 Annual publication performance per project (left) and publication citation performance per project (right). Citations performance includes self-citations

Figure 5.3, at left, shows the average number of publications per projection on an annual basis, where t=0 refers to the year in which the project was completed (i.e. when the thesis was defended). While both groups peak in their graduation year, we see that collaborative doctoral candidates are consistently over-performing, both during project execution as well as after completion. Figure 5.3, at right, shows the citation performance. For both figures, collaborations with firms and collaborations with PROs are combined into one category Also here, performance is consistently higher for collaborative doctoral candidates than for their counterparts, both during as well as after the project ended. While the data underlying this figure includes self-citations, we found similar outcomes when the authors' own citing papers were excluded from the analysis.

Now we turn to patent performance over time. Because we aimed to observe events in the patent system that were as close as possible to the actual moment of invention, for our analysis we used the so-called patent priority year (the year in which the patent application was filed or, in the case of a patent that is part of a family, the year in which the first filing of a patent family member took place). For patent citations, we considered each citation coming into the patent family. To avoid double counting, we considered multiple citations coming from one patent family into the focal patent family as one. The patenting performance reveals rather similar patterns to the ones we saw in publication performance. Collaborative doctoral candidates consistently show a higher performance at any time (Figure 5.4, left) and also incoming (forward) citations of these projects are higher at any time (Figure 5.4, right). The peaks, however, are somehow different than those for publications. Collaborative doctoral candidates have a first patenting peak in their graduation year (presumably patents on inventions arising from the Ph.D. project), and a second peak at four years after project completion.

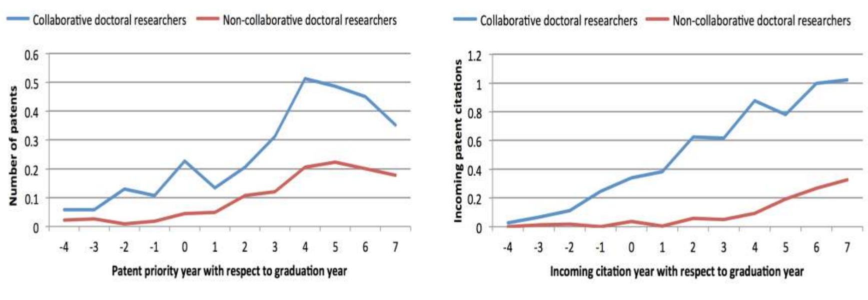

Figure 5.4 Annual patent performance per project (left) and patent citation performance per project (right)

As discussed in Section 5.2, previous studies have focussed on the relationship between patenting and publications, and generally found no negative relationship, or even a positive one. In this study, collaborative doctoral candidates publish at a higher rate and patent more frequently, but the correlation between patenting and publishing rate is not statistically significant, which seems to indicate that the patenting rate neither diminishes nor enhances the publishing rate (see Table 5.3).

Table 5.3 Correlation between patenting and publishing

Variables	**Number of publications**	**Number of patents**
Number of publications	1	
Number of patents	-0.024 (*sig* = 0.613)	1

While we derived the clear results shown above on the high performance of collaborative Ph.D. doctoral candidates compared to their non-collaborative peers, it would be premature to conclude that collaborative projects do better than non-collaborative projects. Possibly, other factors affect project performance as well. Only by controlling for alternative explanations, we can assess the performance effect of collaborative versus non-collaborative projects more precisely.

5.4.3. The determinants of performance differences

Moving beyond the mere observation that collaborative projects have higher performance, we now seek to understand why. Is this higher performance an effect of the collaboration as such, or are there alternative explanations that account for the observed differences? In this section, we first consider differences between different types of collaborative partners, and then investigate alternative explanations for performance differences.

As explained above, our dataset includes collaborations between university and firms as well as between university and PROs. In this section, we will distinguish between the performance in these two categories of collaborative partners. Furthermore, our dataset of firm collaborations includes a considerable number of projects conducted in collaboration with Philips, a very large multinational firm that was originally established in Eindhoven, the same city as in which the university is located at which we collected our data. Philips is known for its long, academic culture, fostering a large research organisation that is still located in this city (see Boersma, 2002). To investigate whether this firms is different from other firms in respect to the performance of collaboration, this section will analyse these collaborations separately.

To better understand to what degree the differences we observe are indeed an effect of collaboration, we looked into a number of alternative explanations. Firstly, we considered the disciplinary nature of the project. Possibly, collaborative projects are over-represented in disciplines with higher publication and patenting rates as well as higher citation rates. By considering the department in which the project was executed, we can correct for differences in publication propensity between academic fields. As discussed in the data section, the doctoral candidates in our data set came from Applied Physics, Chemical Engineering and Chemistry, Electrical Engineering, Mathematics and Computer Science, Mechanical Engineering, as well as four departments involved in management and design. Secondly, we considered whether the doctoral candidate had the Dutch nationality or not (perhaps there are differences in performance rates between Dutch researchers and those with a foreign background, and collaborative projects ‘attract’ one category more than the other). Thirdly, we took into account the candidate’s gender. Finally, we considered whether the supervisor at the university was a ‘star scientist’. Such supervisors not only attract more talented Ph.D. candidates, but they may also improve the performance of their students through tacit knowledge transfer (Buenstorf and Geissler 2014). What is more, star-scientists may collaborate more often with industry, and, if so, may partially explain the high performance of collaborative projects.

For this study, as 'star scientists' we identified all university supervisors who had authored over 200 publications in peer-reviewed journals listed in Elsevier's Scopus database. Out of our 224 doctoral researchers who worked on collaborative projects, 70 candidates (i.e. 31%) were supervised by a total of 20 star scientists. Of our 224 doctoral candidates who did not work on collaborative projects, 55 (i.e. 25%) were supervised by a total of 21 star scientists. These statistics underline the concentration of Ph.D. projects with higher performing supervisors.

The analysis presented in this section is based on a series of negative binomial regression and binary logit regression models, shown in Tables 5.4 and 5.5 (for the choice of negative binomial regression model, see Frenken *et al.* (2005)). The different types of collaborations as well as the alternative determinants of performance are entered as independent variables. Details on the correlation among independent variables can be found in Table A in the appendix. This table shows that none of the variables are highly correlated. As in the previous sections, we measured the performance variables during a time window of four years before and seven years after graduation.

Table 5.4 shows our results concerning academic publication performance. Starting with the publication quantity ('total publications'), Model 1 shows that performance for both firm and PRO collaborations is significantly higher than for doctoral candidates not involved in a collaborative project. However, if we divide the collaborations between Philips and those with other firms (Model 2), we see that the effect for companies can be solely contributed to the Philips collaborations. Apparently, the long academic culture in this company leads to high publication performance (and possibly also the preference of talented doctoral candidates or the best university supervisors to work with this company). Doctoral candidates who worked with other companies do not have a significantly higher number of publications than their non-collaborating peers – but we wish to emphasize that their performance is not significantly lower either. Adding controls for academic disciplines (Model 3) reveals some significant results: the departments of Mechanical Engineering, Mathematics and Computer Science, and the four management or design departments have a lower performance than the Department of Chemical Engineering and Chemistry, the largest department and baseline. Nevertheless, the earlier positive effects of collaborations remain stable. Finally, adding a control for star scientists (Model 4) shows that the supervision by these prolific publishers has a significant positive effect – obviously this comes as no surprise, because both measurements are about the number of publications. The earlier positive effects of collaboration remain stable. (Interestingly, the lower coefficients reveal that Philips works more often with these star scientists than with others.)

Turning to the citation impact of publication (here measured by citation performance), we show the results in Table 5-4, where Models 5-8 focus on citation measurements including all incoming citations. Collaborations with Philips have a higher publication quality, but this is fully explained by the star scientists involved as university supervisors. Collaborations with PROs have a higher publication quality, and this effect is not influenced by university star scientists. Collaborations with firms other than Philips have a publication quality comparable to their non-collaborative peers, not significantly better but also not significantly worse. Models 9-12 present the same analysis as Models 5-8 but exclude self-citations; the results are similar.

Table 5.4 Determinants of doctoral candidates' academic publication performance

Dependent variable →	**Total publications**				**Total citations (including self-citation)**			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**	**Model 7**	**Model 8**
Involved in collaboration with firm	.442 *** (.131)				.126 (.126)			
Involved in collaboration with Philips		.815 *** (.195)	.755 *** (.213)	.589 *** (.213)		.111 (.190)	.602*** (.213)	.209 (.206)
Involved in collaboration with firm (but not Philips)		.149 (.156)	.070 (.158)	.066 (.159)		.135 (.149)	-.008 (.153)	.045 (.153)
Collaboration with PRO	.366 *** (.114)	.366 *** (.114)	.401 *** (.116)	.429 *** (.117)	.224** (.109)	.224** (.109)	.512*** (.115)	.626*** (.113)
Electrical Engineering(a)			.034 (.185)	.223 (.186)			-1.005*** (.184)	-.561*** (.179)
Applied Physics(a)			-.071 (.138)	.067 (.140)			-.812*** (.138)	-.446*** (.138)
Mechanical Engineering(a)			-.289 * (.163)	-.436 *** (.166)			-1.021*** (.158)	-1.306*** (.158)
Mathematics and Computer Science(a)			-.712 *** (.183)	-.422 ** (.189)			-2.270*** (.180)	-1.590*** (.184)
Management and Design(a)			-.624 *** (.206)	-.481 ** (.208)			-1.034*** (.203)	-.996*** (.196)
Candidate is Dutch			-.080 (.110)	-.059 (.110)			.293*** (.110)	.273** (.108)
Candidate is male			.248 * (.135)	.276 ** (.135)			.394*** (.136)	.484*** (.132)
University supervisor is star scientist				.625 *** (.122)				1.263*** (.118)

Notes: Negative binomial regressions; dependent variable measured in -4 to +7 time window (see above text). Standard Error is shown in parentheses. *: 10% significance level; ** 5% significance level; *** 1% significance level. Any value with a significance level of 10% or lower is printed in bold. (a) Baseline is the department of Chemical Engineering and Chemistry, the largest department in terms of collaborations in our dataset.

Table 5.4 – Continued

Dependent variable →	**Total citations (excluding self-citation)[(a)]**				**10 percent of highest cited papers[(b)]**			
	Model 9	**Model 10**	**Model 11**	**Model 12**	**Model 13**	**Model 14**	**Model 15**	**Model 16**
Involved in collaboration with firm	.188 (.126)				-.604 (.512)			
Involved in collaboration with Philips		.108 (.190)	.690*** (.216)	.287 (.207)		-.051 (.647)	.073 (.680)	-.140 (.697)
Involved in collaboration with firm (but not Philips)		.230 (.149)	.089 (.154)	.192 (.154)		-1.097 (.754)	-1.260* (.763)	-1.215 (.765)
Collaboration with PRO	.251** (.110)	.251** (.110)	.606*** (.116)	.737*** (.114)	.280 (.343)	.280 (.343)	.225 (.356)	.185 (.361)
Electrical Engineering(c)			-1.070*** (.185)	-.611*** (.179)			-.680 (.612)	-.403 (.631)
Applied Physics(c)			-.983*** (.139)	-.602*** (.140)			-.186 (.388)	-.042 (.399)
Mechanical Engineering(c)			-1.087*** (.158)	-1.352*** (.158)			-1.359 ** (.651)	-1.503** (.658)
Mathematics and Computer Science(c)			-2.371*** (.179)	-1.666*** (.183)			-.492* (.776)	-1.077 (.799)
Management and Design(c)			-1.068*** (.203)	-1.027*** (.197)			-1.207 (.779)	-1.049 (.785)
Candidate is Dutch			.331*** (.112)	.321*** (.110)			.276 (.379)	.326 (.381)
Candidate is male			.490*** (.135)	.541*** (.131)			.378 (.472)	.324 (.475)
University supervisor is star scientist				1.302*** (.118)				.865** (.353)

Notes: (a) Negative binomial regressions; dependent variable measured in -4 to +7 time window. (b) Binary logit regressions; dependent variable measured in -4 to +7 time window. (c) Baseline is the department of Chemical Engineering and Chemistry, the largest department in terms of collaborations in our dataset. Standard Error is shown in parentheses. *: 10% significance level; ** 5% significance level; *** 1% significance level. Any value with a significance level of 10% or lower is printed in bold.

In Models 13-16, the dependent variable is whether the Ph.D. candidate has produced a highly-cited paper. Such papers indicate scientific "breakthrough" contributions that can have a long-lasting effect on the field in question. Here, one may expect that in-house university project outperform collaborative projects, since in-house university projects, on average, are more focused on fundamental and high-risk research question compared to collaborative projects. In fact, from the descriptive analysis in Table 5-1, we could already observe that the mean citation rate per publication was higher for non-collaborative projects than for collaborative projects. We measure a highly-cited paper by the top-10 percent highest cited papers published in the same year. The results in Model 15 show that in-house university projects (non-collaborative Ph.D. projects) do have some advantage since highly cited papers are less likely when collaborating with firm (except with Philips). This finding is in line with Meyer (2006) who found that university professors who patent, tend to outperform their peers in terms of citations, but not so if looking at the highest cited publications. Our result suggests that scientific breakthroughs, as indicated by highly cited publications, tend to result from in-house Ph.D. projects rather than from collaborative projects. However, in Model 16 when we enter all control variables, considering the dependent variable "being in the 10% best cited paper", it does not matter whether the project is in-house university projects or not. There are no advantages, also no disadvantages for either project. Nevertheless, being in the 10% best cited paper, is positively influenced by the involvement of a university star scientist.

Table 5.5 Determinants of doctoral researchers' patenting performance

Dependent variable→	Total patents				Total citations to patents			
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 1**	**Model 2**	**Model 3**	**Model 4**
Collaboration with firm	1.14*** (.150)				2.301*** (.145)			
Collaboration with Philips		1.709*** (.210)	1.641*** (.217)	1.627*** (.221)		2.912*** (.204)	2.825*** (.225)	2.806*** (.227)
Collaboration with firm (but not Philips)		.590*** (.184)	.658*** (.195)	.665*** (.196)		1.659*** (.171)	1.612*** (.191)	1.647*** (.194)
Collaboration with PRO	.746*** (.136)	.746*** (.136)	.789*** (.152)	.781*** (.154)	1.093*** (.136)	1.093*** (.136)	1.416*** (.163)	1.411*** (.163)
Electrical Engineering(a)			.340* (.205)	.352* (.209)			1.113*** (.210)	1.150*** (.213)
Applied Physics(a)			.032 (.171)	.030 (.171)			-.025 (.175)	-.042 (.176)
Mechanical Engineering(a)			-.287 (.201)	-.300 (.204)			-.052 (.204)	-.092 (.206)
Mathematics and Computer Science(a)			.104 (.219)	.121 (.224)			.420* (.227)	.473** (.231)
Management and Design(a)			-.799*** (.275)	-.790*** (.276)			-.568* (.291)	-.542* (.291)
Candidate is Dutch			.479*** (.142)	.486*** (.143)			1.310*** (.156)	1.363*** (.161)
Candidate is male			.676*** (.182)	.677*** (.182)			.467** (.186)	.484** (.187)
University supervisor is star scientist				.053 (.151)				.185 (.157)

Notes: Negative binomial regressions; dependent variable measured in -4 to +7 time window (see above text). Standard Error is shown in parentheses. *: 10% significance level; ** 5% significance level; *** 1% significance level. Any value with a significance level of 10% or lower is printed in bold. (a) Baseline is the department of Chemical Engineering and Chemistry, the largest department in terms of collaborations in our dataset.

In Table 5.5 we present a similar analysis, but now focusing on patenting performance. Again we look at quantity (the total number of patents by the doctoral candidate) and the impact of these patents (proxied by the forward citation score). Here, the effect of collaboration is stronger than with publications – not entirely surprising, because commercial collaboration partners have stronger incentives to get patents from their research than universities. All types of collaborations (with Philips, with firms other than Philips and with PROs) perform significantly better, both in quality and impact, and adding the alternative explanations does not remove any of these significant effects.

5.5. Conclusions, limitations and policy implications

Our study shows that doctoral candidates involved in collaborative Ph.D. projects achieve a higher performance than non-collaborative Ph.D.s projects in respect of all the performance dimensions we studied: the number of (peer reviewed) publications, the citation score of these publications, the number of applied patents, and the number of forward citations of these patents. We observed this higher performance both during the Ph.D. project as well as in the ensuing seven years. A deeper investigation of the determinants of this improved performance revealed that they firstly depend strongly on the nature of the collaborative partner. Secondly, the numerous collaborations in our data set with Philips, a firm with a long academic culture, displayed a higher performance, as well as Ph.D. projects with PROs. Collaborations with other firms, however, showed no significant performance differences with non-collaborative peers: they were not significantly better (but not significantly worse either). Thirdly, university supervision by a 'star scientist' makes a notable difference, but generally did not alter the significance of the other determinants.

An important methodological limitation of our study is that we did not establish a causal effect of industry involvement on output performance. Indeed, the positive effects found may solely be due to self-selection by students, where the brighter and more motivated students opt more often to work in collaborative Ph.D. projects compared to other students. Indeed, such self-selection effects may be present as a collaborative Ph.D. projects offer an additional reward upon completion: collaboration with industry provides the Ph.D. candidate with an additional career option as (s)he can easily enter both academia and industry afterwards. Hence, on average, the brighter students may be drawn more often to Ph.D. projects with industry. To some extent, we controlled for talent by taking into account star-scientists. One can expected that brighter students are more drawn to star-scientists. Hence, though very imperfect, the star-scientists dummy not only proxies the university supervisor's talent, but also - at least to some extent - the student's talent.

But whatever the exact causes of the higher performance Ph.D.'s engaged in collaborative projects, our main policy conclusion still holds: our study does find ground for concerns by universities (and agencies funding Ph.D. projects) that industry involvement decreases academic output. Collaborative projects do not have a lower performance, and in many cases even a significantly higher performance. Hence, the university are advised to further stimulate industry collaborations, as well as collaborations with PROs, and we see no reasons for universities to be reserved to enter into such collaborations when such opportunities arise. Taking the particularly positive effects of Philips collaborations in mind, universities could also put particular emphasis on entering into collaborations with firms or institutes with a long-standing academic / research tradition, rather than firms less experienced in performing research themselves. One could think of firms that have been having institutionalized research labs for a long time, and/or firms whose research staff has been proliferate in publications in academic journals.

From the perspective of a university, following the possible role of self-selection, having industry involved in Ph.D. projects may actually be a way to attract talented Ph.D. candidates in the first place, insofar these students want to retain the option to make a career in industry afterwards. Also, it may help to attract candidates that are already working in industry and for which the company is willing to finance the Ph.D. in return for a collaborative project. Without providing opportunities for collaborative projects, some of these students may do no Ph.D. project at all. Clearly, all these questions are interesting avenues for future research.

Being conducted in a specific setting, it is important to consider to which degree our results may be generalized. Firstly, specific aspects of the Dutch context may have affected the outcome. As a result, they may much closer to incentives and behaviour than their counterparts in other countries. Secondly, specific aspects of the Eindhoven University of Technology, where we collected our data, may play a role. As indicated earlier, we chose to collect data at one single institute in order to avoid institutional differences that would result in unexplained variance, and because we wanted to focus on an institute where such collaborations were common (giving us sufficient data to enable analyses). We acknowledge that other institutes might differ. There might be formal differences (although we are not aware of university or departmental policy or practice that would impact our findings), cultural differences, and contextual differences (the status of the university in a wider network of actors).

5.6. Appendix

Table A Correlation between independent variables

Independent variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Involved in collaboration with firm (1)											
Involved in collaboration with Philips (2)	.557§										
Involved in collaboration with firm (but not Philips) (3)	.767§	-.106#									
Collaboration with PRO (4)	-.327§	-.182§	-.251§								
Electrical Engineering (5)	.199§	.220§	.068	-.165§							
Applied Physics (6)	-.064	.014	-.088*	.134§	-.217§						
Mechanical Engineering (7)	-.096#	-.115#	-.026	.098#	-.152§	-.246§					
Mathematics and Computer Science (8)	-.006	.062	-.055	-.086*	-.214§	-.133§	-.151§				
Management and Design (9)	.010	-.150§	.128§	-.019	-.224§	-.362§	-.254§	-.222§			
Candidate is Dutch (10)	-.005	.036	-.034	-.033	-.038	.077	.047	-.028	-.067		
Candidate is male (11)	.053	.000	.063	.016	.052	.036	.006	-.058	-.002	.135#	
University supervisor is star scientist (12)	-.023	.021	-.043	.101#	-.050	-.050	.233§	-.225§	.134	-.067	.018

‘*’: $p<0.10$; ‘#’: $p<0.05$; ‘§’: $p<0.01$

Phi coefficient was used to measure the association between dichotomous variables

6. Conclusions

I have been a seeker and I still am, but I stopped asking the books and the stars. I started listening to the teaching of my soul. Molana

Abstract

By providing a conceptual research framework for Ph.D. collaboration that has been tested and validated by three main empirical studies, this thesis contributes significantly to the literature of university-industry relationships. This chapter describes in more depth the main contributions of this thesis and how universities and industry can benefit from the findings, based on empirical studies. Section 6.2 describes the outcomes of these studies. The contributions of the thesis are discussed in Section 6.3, followed by a presentation of the managerial implications (Section 6.4). Finally, Section 6.5 elaborates on the limitations of this study and outlines some future research avenues.

6.1. Introduction

In the past decade, there has been a surge in studies on university-industry collaborations. While much of the existing literature focuses on the role of technology transfer offices, intellectual property creation and academic entrepreneurship (Perkmann *et al.*, 2013), the study of collaborative Ph.D. projects between university and industry and between university and a Public Research Organization (PRO) has been almost entirely neglected. This is perhaps surprising given that such collaborations can be quite common. For example, at Eindhoven University of Technology in the Netherlands, which features in this study, almost one third of all Ph.D. projects are collaborative, either with industry or PROs. The first aim of my thesis is to fill the gap identified in the literature by looking at the motivations and governance structures of collaborative Ph.D. projects and to what extent the governance mode affects project success. The second aim is to study the potentially harmful effects of increasing industry involvement in Ph.D. projects. In particular, concerns have been raised that such joint projects, though beneficial for industry, may harm the academic quality of Ph.D. projects and post-Ph.D. academic careers.

The following overall research question was formulated:

How can we explain the various modes of governance of joint Ph.D. projects between university and industry, and what factors drive the success of such collaborative projects?

After reviewing the literature of governance and success in the joint collaborations between universities and industry in Chapter 2, this study considered the following sub-questions:

1. How do universities and industry govern joint Ph.D. projects? (Chapter 3)
2. How do these governance choices impact successful outcomes? (Chapter 4)
3. How does the output performance of doctoral candidates in joint projects differ from their non-collaborative peers? (Chapter 5).

To address these research questions, three main empirical studies have been conducted.

6.2. Main findings

6.2.1. Determinants of governance mode choices

Chapter 3 investigates how universities and firms/PROs govern collaborative Ph.D. projects. The aim is to discover under which conditions partners select different modes of governance. More specifically, it examines how the distance between partners in social, cognitive and geographical dimensions and resource imbalances affect the choice whether to adopt a shared or centralized governance mode.

Table 6.1 shows the statistically significant determinants of governance modes. We see that shared management is more likely when social distance (first-time collaboration) is high, and when a university's partner (firm or PRO) funds the projects. Centralized management, in contrast, is more likely when the geographical distance is large, or the university holds critical resources. These findings are all in line with the expectations derived from proximity and resource theories, apart from the effect of social distance, which could lead to centralized governance due to a lack of trust in first-time relationships. Regarding decision-making, I found that geographical or cognitive distance has a negative impact on shared decision-making, which corresponds with the proximity framework.

The table also shows that the involvement of a firm, unlike a PRO, increases the probability of both shared management and decision-making. This may indicate that PROs have more bureaucratic structures than most firms, and consequently prefer not to adopt a shared governance mode where roles and responsibilities are less clearly defined.

Finally, I consider in what situations publication restrictions occur. Geographical distance tends to increase publication restrictions. Concerning funding, the results show that where projects are funded by the university's partner or even by the university itself, publication restrictions increase. While we might expect to encounter restrictions where the partner provides funding, the reason why universities also sometimes decide to pose such restrictions is unexpected and difficult to interpret. Finally, as we might expect, if the university's partner is a firm (as opposed to a PRO), the likelihood of posing publication restrictions is higher.

Table 6.1 Impact of proximity and resource variables on governance modes

	Governance mode						
	Centralized	Centralized	Shared	Centralized	Centralized	Shared	
Dependent variable	**University manages**	**Partner manages**	**Both manage**	**University decides**	**Partner decides**	**Both decide**	**Publication restriction**
Distance variables							
Geographical distance	+		–			–	+
Social distance			+		–		
Cognitive distance						–	
Resource variables							
University holds critical resources	+	–		+	–		
University's partner holds critical resources					+		
University funds the project itself							+
University's partner funds the project	–		+				+
Other variables							
Industry involvement[1]		–	+	–		+	+

[1] Means the university's partner is a firm as opposed to a public research organization.

6.2.2. How governance is related to success of collaborative Ph.D. projects

The second empirical study in this thesis (Chapter 4) investigates the impact of governance characteristics on the success of collaborative Ph.D. projects. That success was measured using a multi-dimensional scale to investigate the impact of three main aspects of governance (project management, supervision, and communication within project). Table 6.2 presents the main findings regarding different aspects of governance. This table summarizes three separate regressions on the effects of project management, supervision and communication characteristics on project performance, respectively.

Regarding project management variables, the findings suggest that knowledge transfer is more likely if both partners are involved in decision-making, or the university's partner imposes publication restrictions. Regarding patenting, the results show that if the university's partner funds the project or poses publication restrictions, the likelihood of patenting increases, as we might expect. A job offer by a university is less likely if the university's partner is involved in managing the relationship (either alone or together with the university). Finally, collaborations tend to be followed up if the university's partner is the funder.

Table 6.2 The impact of various governance aspects on collaboration success

	Level of knowledge transfer	Resulted in academic publication	Knowledge was patented	Subsequent job offer from university	Subsequent job offer from partner	Collaboration was followed up
			Project management			
Funding funded by partner			+			+
Relationship managed by partner				–		
Relationship managed by both			–	–		
Decision-making by partner						
Decision-making by both	+					
Publication restriction imposed by partner	+		+			
			Supervision			
Level of university supervisor knowledge	–				–	
Level of partner supervisor knowledge						
Level of university supervisor enthusiasm			+			
Level of partner supervisor enthusiasm						
Similar opinions between both supervisors	+					
Supervisor replacement	–					
Openness of university supervisor						
Openness of partner supervisor						
Academic position of daily university supervisor		–				
Academic degree of partner supervisor						+

Communication						
Meeting frequency of Ph.D. candidate and university supervisor						
Meeting frequency of Ph.D. and partner supervisor					+	
Meeting frequency of both supervisors						+
Quality of communications between Ph.D. and university supervisor					+	
Quality of communications between Ph.D. and partner supervisor	+					

Looking at supervisors' characteristics, we see that similarity of opinions supports knowledge transfer, while a too high knowledge level of the university supervisor and supervisor replacement hamper knowledge transfer. Publication output is more likely if the university supervisor is not too highly ranked. The level of knowledge transfer is positively influenced by similar opinions between supervisors both at the university and its partner.

Patenting increases with the university supervisor's enthusiasm, while a job offer by the partner is less likely with a high knowledge level of the university supervisor. Finally, collaboration follow-up is more likely if the university partner's supervisor has a high academic degree.

We see that communication only has a minor impact. The quality of meetings between the Ph.D. candidate and university partner's supervisor increases the likelihood of knowledge transfer to that partner, as we might expect. A job offer from the university's partner is more likely if there is a high frequency and high quality of meetings between the Ph.D. candidate and the partner's supervisor, again, as expected. Finally, the chances of a follow-up collaboration increases if supervisors meet frequently.

In each of the three regressions (on project management, supervision and communication), the regression analysis also included four control variables: geographical proximity, whether the partner was a firm or PRO, whether the Ph.D. candidate was a former employee of the partner, and whether partners had collaborated before. Here, the main findings are that the chances of patenting increase if partners are geographically proximate and if the university's partner is a firm rather than a PRO. Another noteworthy finding is that Ph.D. candidates previously employed by the university's partner, consistently increase the amount of knowledge transferred to that partner. Thus a former employee who enters a Ph.D. project provides an effective channel for knowledge transfer from the university to the partner organization.

6.2.3. Comparing performance of collaborative and non-collaborative Ph.D. projects

The third empirical study (Chapter 5) analyses the effects of university-industry collaborations on patent and publication output compared to in-house university Ph.D. projects. The comparative study used bibliometric data and the comparison was based on the numbers of (peer reviewed) publications, citations of these publications, applied patents, and forward citations of these patents. The Ph.D. candidates involved in collaborative Ph.D. projects (compared to non-collaborative Ph.D. candidates) show a higher performance during their Ph.D. study. It is worth mentioning that such superiority apparently remains after the candidates graduate.

A deeper investigation of the determinants of this superiority highlights the significance of the type of university partner. Collaboration with Philips, a firm with a long academic culture, as well as with PROs, displayed significantly higher performance, while collaborations with firms other than Philips were neither significantly better, nor significantly worse. The potential effect of university supervision by a 'star scientist' was also investigated, and proved to have a significant effect on Ph.D. project performance. Thus the concerns about the negative effects of industry involvement on the academic quality of Ph.D. thesis seem unfounded, at least for a university like Eindhoven University of Technology (TU/e).

6.3. Scientific implications

This thesis contributes to the literature of university and industry relationships in a variety of ways. First of all, broadly speaking, the existing literature has analysed the various knowledge transfer channels between university and industry. However, as the literature review (Chapter 2) clarifies, there are few studies of collaborative Ph.D. projects, despite these being considered a major channel of knowledge transfer. Such projects take place over a substantial period of time (generally four years) and judging from our data, are rather common at least at TU/e. As such, the main contribution of this study is to focus on this channel of university-industry relationships, proposing a research framework adapted to the specifics of such interactions.

The proposed framework consists of a comprehensive model for collaborative Ph.D. projects, including the various characteristics of collaboration governance, the determining factors of governance modes chosen by collaboration partners, and the success of Ph.D. collaborations. The relationship between these elements of the model has been hypothesized and tested using empirical studies. A specific contribution in this respect is the creation of a multi-dimensional construct of success, doing justice to the complex and multifaceted nature of collaborative Ph.D. projects. Another important contribution is the additional use of bibliometric data to assess the success of Ph.D. collaborations from different perspectives (academic: publications and citations to publications; commercial: patents and citations to patents). These considerations clearly provide a more complete picture of success.

Finally, this thesis provides insights from several comparison analyses between collaborative and non-collaborative Ph.D.

projects. The specific aim is to investigate the claim that industry involvement crowds out academic output (which was found to be ungrounded). The investigation into this issue contributes to the literature on academic patenting (as reviewed in Chapter 5), because similar concerns have been raised that university patenting may come at the cost of lower academic output.

Overall, this thesis, by providing a conceptual research framework for Ph.D. collaboration that has been tested and validated by various empirical studies, significantly enhances the literature of university-industry relationships.

6.4. Managerial implications

The outcomes of this study are also relevant from a managerial perspective. We have seen the numerous ways in which universities and industry can increase collaboration success. The main managerial implications are:

- Universities and collaborating partners need to be more critical when choosing partners for joint Ph.D. projects. For example, geographical and cognitive proximity (similar knowledge levels) seems to be important for success. In both cases, a shared governance mode becomes more likely, which in turn increases the probability of a project's success. Partners are also advised to share decision-making and project management as much as possible, unless specific circumstances apply (such as access to critical resources). In line with other studies, the distribution of authority among partners enhances the flexibility, creativity and efficiency of the collaborative effort (Shrum *et al*., 2007).
- Universities are recommended to engage in joint projects funded by industry. This provides a situation for university researchers to do more research without compromising academic quality (Gulbrandsen and Smeby, 2005). The results also stress the importance of active engagement of

supervisors, especially university supervisors, in the project. University partners are recommended to increase the motivation and enthusiasm of supervisors to be more actively involved in the project and avoid replacing them during the project. Furthermore, because of the importance of physical and face-to-face communication in transferring tacit knowledge (Nonaka, 2005) and the important role of Ph.D. candidates in knowledge transfer, the collaborating partner is advised to oversee the frequency and quality of communication with the Ph.D. candidate during the project. Obviously, this would be facilitated by geographical proximity, but can, in principle, also be done at longer distance by organizing “temporary geographical proximity” (Torre, 2008), through travel and short stays. Finally, partners are advised to consider the importance of previous experience of collaboration before choosing each other as a partner. In fact, previous collaboration experience between the two partners creates trust (Bouba-Olga *et al*., 2012), and helps to achieve a higher level of success (Hahn *et al*., 2008). Ph.D. candidates who were previously employed by the university’s partner, proved to be particularly effective channels for knowledge transfer from the university to the partner organization.

- The results also contribute to the on-going policy debate regarding the possible negative effects of industry involvement in academic research (Perkmann *et al*., 2013). In contrast with the literature showing that involving industry can cause delays in publications (Nelson, 2004), our analysis did not find such a delay. The publication output and impact of collaborative Ph.D. projects was not lower than in-house university Ph.D. projects, as some may have expected. Less surprisingly, collaborative Ph.D. projects yield more patents than in-house university projects. Hence, universities (and government funders) do not need to worry that collaborative projects could lead to less scientific output, at least from a university like TU/e.

6.5. Limitations and future research

6.5.1. Research scope and limitations

The following is a summary of the scope and limitations of this study.

- This study was conducted at one technical university (TU/e) in the Netherlands, not in other universities or in other countries. The data was collected at one single university in order to reduce the variance stemming from inter-organizational differences. Moreover, TU/e was chosen because of its extensive track record collaborating with industry in technological research. An international ranking[1] lists TU/e as the number one university (worldwide) with the highest number of publications co-authored with industrial partners. This suggests TU/e is an untypical university of technology, possibly as a result of the regional ecosystem in which it is embedded. Focusing on TU/e as a single university increases the limitations of the potentially strong regional effect of a particular institutional and cultural context (Cooke *et al*., 1997; Asheim *et al*., 2011). TU/e is based in the 'Brainport' region, often labelled as a 'high-trust' setting which facilitates and promotes industry-university collaboration. The Eindhoven-Brainport region hosts many high-tech firms including Philips, ASML (the world's leading firm in lithography for computer chip production), FEI (a leading specialist in transmission and scanning electron and ion

[1] http://www.tue.nl/en/university/news-and-press/news/tue-again-number-1-worldwide-in-research-with-industry/

microscopy) and NXP (a large semiconductor manufacturer). The intensive collaboration with industry, also reflected in a significant number of Ph.D. collaborations, enabled the construction of a database large enough to address the research questions. Thus the results of this study might be limited by characteristics of country, type of university and specific disciplines, and so may not be generalizable to other regions, particularly those lacking a high-trust institutional context. Indeed, TU/e has no strict guidelines on Ph.D. collaborations, which allows faculty members a large degree of freedom to design their collaborations. Hence, to be able to generalize the results for other institutions, other national contexts and other disciplines, future studies need to replicate our analyses in different settings.

- The focus is on former Ph.D. candidates who successfully completed (defended and published) their theses, which limits the generalizability of findings to these Ph.D. projects and not those that failed to be completed. The choice of completed theses was driven by practical constraints (only completed Ph.D. projects are well documented by the university).
- As the probability of obtaining completed survey questionnaires from all partners is very low, the relationship between governance and collaboration success was only measured from the Ph.D. candidate perspective.
- It would also be interesting to consider collaborative Ph.D. projects in which a university collaborates with government agencies (such as ministries) or other universities. Such collaborations are not included in this analysis. If organizations such as governments and partner universities had been included, the sample would have become very heterogeneous, given their quite different goals, incentives

and behaviour compared to firms and PROs. In contrast, PROs and firms are similar in many respects, at least in the Dutch context. Additionally, the absolute number of collaborations with government agencies in the total population would probably have been too low to control for effects related to government.

- An important methodological limitation of the comparative study on collaborative versus non-collaborative Ph.D. projects (Chapter 5) is that no clear *causal* effect of industry involvement of output performance could be established. Indeed, the positive effects found for industry involvement in performance may be solely due to self-selection by students ─ brighter and more motivated students opt more often to work in collaborative Ph.D. projects, especially with Philips, compared to other students.

6.5.2. Future research

Suggestions for new research avenues to extend the scope of this study are as follows:

- Measuring the effect of self-selection by students

As noted, an important methodological limitation of this study is that no causal effect of industry involvement on output performance was established. Indeed, the positive effects of industry involvement may be due to self-selection by students because collaborative Ph.D. projects offer an additional reward upon completion: collaboration with industry provides Ph.D. students with valuable options as they can easily enter both academia and industry afterwards. Following this self-selection, involving industry in Ph.D. projects may be a way to attract talent to a Ph.D. project in the first place, insofar these are students who want to retain the option of a career in industry afterwards. Without the opportunity for a Ph.D. project with industry, some students may not engage in a Ph.D. project at all. Hence, a promising research avenue is to analyse in detail the exact motivations for students to enter into a Ph.D. project, and what personal characteristics drive students to choose in-house university or collaborative projects with either a firm or a PRO.

- Measuring the efficiency of collaborative Ph.D. projects

If we consider different outputs for collaborative Ph.D. projects (e.g. publication, patent, citation), and consumed resources as inputs (e.g. duration of Ph.D. study, knowledge of supervisors), then we can measure the *efficiency* of a collaborative Ph.D. project by considering the ratio of outputs over inputs. “Economists say that a producing unit is ‘technically inefficient’ if it is possible to produce more output with the current level of inputs or, equivalently, it is possible to produce the same output with fewer inputs,” (Thursby and Kemp, 2002, pp.109-124). Therefore it seems a collaborative Ph.D. project may be inefficient if it consumes more resources (as we might expect) while yielding similar academic output. In the context of university-industry relationships, the efficiency of university technology transfer has already been studied by Anderson *et al*. (2007) and the efficiency of university intellectual property licensing has been considered by Thursby and Kemp (2002). However, the efficiency of more interactive channels of university-industry collaboration such as collaborative Ph.D. projects is still an open question in the literature.[1]

- University selection process

Universities are among the most important partners for firms aiming to achieve a sustained competitive advantage and are also considered an engine of economic growth by policymakers (Siegel

[1] One method suggested for measuring efficiency is Data Envelopment Analysis (DEA), a linear programming approach (Anderson *et al*., 2007).

and Phan, 2005). As mentioned earlier, university and industry tend to collaborate more and more through different channels, with varying success rates. We have seen the important role a well-defined governance structure plays in achieving successful collaborative Ph.D. projects. Moreover, selecting the most suitable partner is another challenge which can influence the success of collaboration. If a firm cannot select the most suitable university as partner, several problems could cause the collaboration to fail. A firm should be able to evaluate different universities in order to make an informed choice about the best candidate. This evaluation is based on criteria such as the university's research and commercialization competencies, geographical proximity between university and firm, and a university's willingness to engage in collaboration. We can formulate this as multi-criteria decision-making (MCDM problem), and propose an MCDM method to resolve the issue.

- University relationship management[1]

As mentioned earlier, the choice whether to collaborate between firm and university through joint research, publishing, patenting, licensing or sharing facilities is determined by factors such as collaborating partners' motivations and facilitators. However, we can distinguish different types of interaction channels based on specific characteristics in terms of levels of interaction, integration, trust, commitment, and joint decision-making. For instance, participation in conferences as one form of interaction requires only a limited involvement of collaboration partners for a short period. That is to say, after the conference finishes, the relationship between university and firm is likely to end. In R&D projects,

[1] An introductory overview of this idea is presented in Salimi, N., and Rezaei, J. (2013). University Relationship Management: An Introductory Overview. 19th IEEE & ICE-ITMC International Conference on Technology and Innovation Management, June 24-26, 2013, The Hague, The Netherlands.

however, it is necessary to involve both collaboration partners' more functional areas. In this type of collaboration the level of components (characteristics) such as mutual trust, openness, shared risk and rewards should be high. Therefore, firms and universities must apply different management strategies to manage and control the level of these components. Managing the components of the firm-university relationship, which can be referred to as university relationship management (URM), is an important strategic activity that has not been covered in the literature of university-industry collaboration.

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Appendix: Questionnaire

A. Please fill in the following questions about yourself.

1. Your personal information

Your name (first name, last name):

Your nationality:

- Dutch
- Other (please specify):

Your gender:

- Male
- Female

2. In what year did you defend your Ph.D. project?

(Pre-coded from 2000 to 2011)

3. How many years was the agreed time schedule for your Ph.D. project?

(Pre-coded “3 years” to “more than 7 years”)

4. How many years did you work on your Ph.D. project?

(Pre-coded “3 years” to “more than 7 years”)

5. What was your city and country of residence during your Ph.D. project: _______________

B. Please fill in the following university information.

6. In what university department did you perform your Ph.D. project?

- Applied Physics

- Biomedical Engineering
- Architectural Science
- Chemical Engineering
- Electrical Engineering
- Industrial Design
- Industrial Engineering and Innovation Sciences (including former Technology Management)
- Mathematics and Computer Sciences
- Mechanical Engineering

7. Name and positions of your university supervisor(s) when you started your Ph.D. project? *(Note: professor includes 'bijzonder hoogleraar' and 'buitengewoon hoogleraar')*

	Name	Assistant professor	Associate professor	Professor
Your promoter				
Your daily supervisor				

8. Have you been involved with the TU/e *before* the start of your Ph.D. project?

- No
- I did a Master or Bachelor study at the TU/e
- I worked as an employee at this university
- I performed collaborative research with the TU/e (but was not working there)
- Other (please specify):

C. Please fill in the following questions about the collaborating partner:

Note: a collaboration is a project in which partners actively participate. A pure funding role for instance by NOW or STW does not constitute a collaborating partner

9. Your Ph.D. project was a collaboration between the Eindhoven University of Technology and …
- A firm, please mention its name:
- A public research organization, please mention its name:
- Another university, please mention its name:
- A government body, please mention its name:

10. City and country of the offices of the collaborating partner where your supervisor was located:

11. Please indicate the number of employees of the collaboration partner (worldwide):
- 1-9
- 10-49
- 50-250
- More than 250
- Don't know

12. Please select the economic activity that best characterizes the collaborating partner:
- Research and development (R&D)
- Supplying products to the market
- Supplying services to the market
- Distribution
- Design
- Consultancy
- Policy making
- Other (please specify):

13. Scientific degree of your (main) supervisor at the collaborating partner when you started your project. (*Note: Full professor includes ‘bijzonder hoogleraar’ and ‘buitengewoon hoogleraar’)*

- Bachelor or Master
- Ph.D.
- Professor at the TU/e
- Professor, elsewhere

14. Did you have a previous relation with the collaborating partner before your Ph.D. project? (if applicable, you may select more than one option)

- No
- I did a traineeship or Master thesis project at this organization
- I worked there as an employee
- I performed collaborative research with this organization
- Other (please specify: ____________)

D. Please fill in the following General information on your Ph.D. project.

Please fill in the following questions (if applicable, you may select more than one option):

15. By whom were you employed during your Ph.D. project?

- By the university
- By the collaborating partner
- By both university and collaborating partner (two separate work contracts)
- By none; I had a personal scholarship or funds
- Other (please specify):

16. Who funded your Ph.D. project? (Please choose the best matching answer)
    - The university own funds (‘first flow of funds’, ‘eerste geldstroom’)
    - A funding organization (e.g. NWO, STW)
    - The collaborating partner (either by direct employment or by a contract to the university)
    - None (e.g. personal scholarship etc.)
    - Other (please specify):

17. Where did the original idea for the topic of your Ph.D. project come from? (Please choose the best matching answer.)
    - Yourself
    - The university
    - The collaborating partner
    - Combination of university and collaborating partner on the basis of previous or on-going collaborative activities
    - Other (please specify):

18. Was your work building directly upon earlier patented technology?

- No
- Yes, on patent(s) invented by yourself
- Yes, on patent(s) invented by university staff
- Yes, on patent(s) invented by staff of the collaborating partner
- Yes, on patent(s) invented by a third party

E. Motivations of you, the university and the collaborating partner.

19. How important were the following possible motivations for you to engage in this collaboration?

	Very low	Low	Medium	High	Very high
Future job prospects					
Interest in specific research topic					
Satisfaction and useful experiences by working with industry or other partners					
Access to valuable or unique data or research facilities (e.g. laboratories, equipment)					

20. How important were the following possible motivations for the collaborating partner to engage in this collaboration? (as far as you can determine)

	Very low	Low	Medium	High	Very high	Do not know
Access to valuable or unique data or research facilities at the university (e.g. laboratories, equipment)						
A need for a very specific piece of knowledge to fill an existing knowledge gap (e.g. for a certain product or production process)						
A more general increase of the longer-term stock of knowledge of the organization in a specific area						
Satisfying the expressed ambition of the candidate (you) for doing a Ph.D. (in case you were employed by the collaborating partner prior to the Ph.D. project).						
Creating and maintaining linkages to universities						

21. How important were the following possible motivations for the university to engage in this collaboration? (as far as you can determine)

	Very low	Low	Medium	High	Very high	Do not know
Access to valuable or unique data or research facilities at the collaborating partner (e.g. laboratories, equipment)						
Receiving funding from the collaborating partner						
Interesting or practically relevant research topic						
Alignment of university research with industry needs						
Contributing to the regional or national economy						
Creating and maintaining linkages to the industry						

F. Please fill in the following questions about the supervision.

22. Prior to your Ph.D. project, have the supervisors from the university and from the collaborating partner worked together (e.g. research, projects or collaborations)?
- No
- Yes
- Don’t know

23. Please answer the following questions:

	Very low	Low	Medium	High	Very high	Not applicable	Do not know
How would you rate the **knowledge** of your university supervisor(s) in the specific topic of your Ph.D. study?							
How would you rate the **knowledge** of your supervisor(s) at the collaborating partner in the specific topic of your Ph.D. study?							
How would you rate the **enthusiasm/personal involvement** of your university supervisor(s) in the specific topic of your Ph.D. study?							
How would you rate the **enthusiasm/personal involvement** of your supervisor(s) at the collaborating partner in the specific topic of your Ph.D. study?							
To what degree did the supervisor(s) at university and those at the collaborating partner usually agree (or have similar opinions) about choices concerning the project?							

G. Please fill in the following questions about Project management.

24. Did the university and the collaborating partner make explicit agreements (like in a contract or an agreed letter) about the project, such as the topic, the research objectives, and research approach?

- No
- Yes

25. Was a project time table and/or a list of project deliverables was agreed upon in advance of the project?

- No
- Yes

26. While conducting the research, did you come to the conclusion that significant changes would be required to the topic, the research objectives, and research approach? Did the university and the collaborating partner agree to implement such changes?

- No
- Yes, but partners did not agree to implement such changes
- Yes, and partners agreed to implement such changes

27. Was any of your supervisors replaced during the course of your Ph.D. project?

- No
- Yes, please indicate why: ____________________

28. Which organization was most prominent in managing the coordination or relationship?

- The university
- The collaborating partner
- Both to the same degree

29. From where were you actually working on a daily bases?

- Mostly from the offices at the university
- Mostly from the offices of the collaboration partner
- More or less equally from both offices
- Elsewhere (please specify):

30. Please indicate the average frequency of *supervision meetings* you had with (any of) the supervisors at the collaborating partner *(Note: this is about supervision meetings, not about other events in which you met these persons)*

- More than once a week
- About every week
- About every two weeks
- About every month
- About every 3 months
- About every 6 months
- Less than every 6 months

31. Please indicate the average frequency of *supervision meetings* you had with (any of) your university supervisors. *(Note: this is about supervision meetings, not about other events in which you met these persons)*

- More than once a week
- About every week
- About every two weeks
- About every month
- About every 3 months
- About every 6 months
- Less than every 6 months

32. What was the frequency of meetings where *both* the supervisors of the university and the supervisors at the collaborating partner were present?

- About every month
- About every 3 months
- About every 6 months
- About every year
- Less than every year

33. How was the decision-making in the project best characterized?

- Mostly done by university
- Mostly done by the collaborating partner
- Joint decision-making with an equal involvement of both partners

34. Please answer the following questions:

	Very low	Low	Medium	High	Very high	Not applicable	Do not know
To what degree did your university supervisor(s) was open to any idea or change in the project?							
To what degree did your supervisor(s) at the collaborating partner was open to any idea or change in the project?							
How would you rate the quality of communication between you and your university supervisor(s)?							

How would you rate the quality of communication between you and your supervisor(s) at collaborating partner?							
How would you rate the willingness of both the university and the collaborating partner to share sensitive and/or confidential information, when necessary?							
To what degree were you restricted to publish or disclose research finding because of the commercial interests of the collaborating partner?							

H. Please fill in the following questions about characteristics of you scientific field

35. Please indicate the importance of the following types of knowledge in your scientific field

	Very low	Low	Medium	High	Very high	Not applicable	Do not know
Basic knowledge (i.e. knowledge developed without a specific application in mind, like general theories)							
Applied knowledge (i.e. knowledge developed with a specific application in mind)							

36. Do you expect that your scientific field will bring forth main (technological) breakthroughs within the coming 5 years?

- No
- Yes

37. How would you, in general, characterize the knowledge in your scientific field?

- Stand-alone (i.e. knowledge and findings can be applied relatively independent form other knowledge)
- Systemic (i.e. knowledge can only be applied if one also utilizes many other research findings).

I. Please fill in the following questions about outcome and utilization of the Ph.D. project

38. Please indicate the extent to which the knowledge you developed in your Ph.D. thesis has been taken up **by the collaborating partner**. Please select the highest appropriate item in this progressive scale.

- Not transferred at all
- Transferred the knowledge (is now effectively available to its staff working in this field, for instance in the library, or has been presented to the staff)
- Absorbed the knowledge (i.e. its researchers have studied and now master this knowledge)
- Applied the knowledge in a business context
- Commercialized the knowledge as a (smaller) element of a product or process
- Commercialized the knowledge as the main basis or element or of a product or process

39. Suppose a third party would like to use your findings for a product or service.

- This would be possible just on the basis of the information provided in the Ph.D. thesis
- As above, but your personal involvement would be beneficial to them because you can offer information and insights that could not be laid down in the thesis itself.
- This would certainly require your personal involvement, the information and insights you can offer are indispensable for actual usage.

40. Did your Ph.D. project result in scholarly publications in academic journals?

- No
- One publication (please provide the name of this journal)
- Two publications (please provide the name of this journals)
- Three publications (please provide the name of this journals)
- More than three publications (please provide the name of this journals)

41. Were there research results that could not be published because the collaborating partner wished to keep these confidential?

- No
- Yes

42. Did your Ph.D. project result in a patent or patent application with you as a listed inventor?

- No
- Yes, and the patent was assigned to the university
- Yes, and the patent was assigned to the collaborating partner

43. Please indicate below the levels of satisfaction of the various parties

	Very low	Low	Medium	High	Very high
How satisfied do you feel yourself with the outcome of the Ph.D. project?					
How satisfied do you believe the university department feels with the outcome of the Ph.D. project?					
How satisfied do you believe the collaborating partner feels with the outcome of the Ph.D. project?					

44. Please feel free to comment further on the degree of satisfaction:

J. Please fill in the following questions about after the conclusion of your Ph.D. project.

45**.** After your Ph.D. project was finalized, did the university offer you a position?

- No
- Yes, but you did not accept it
- Yes, and you accepted it

46. After your Ph.D. project was finalized, did the collaborating partner offer you a position?

- No
- Yes, but you did not accept it
- Yes, and you accepted it

47. After your Ph.D. project was finalized, did the university and the collaborating partner get engaged in a new collaboration?

- No
- Yes, but this was not a direct follow-up of your Ph.D. project.
- Yes, and this was a direct follow-up of your Ph.D. project.
- Don't know

48. After your Ph.D. project was finalized, did the firm continue or start internal research activities following your work?

- No
- Yes
- Don't know

49. Are there any comments you would like to share about your Ph.D. project or about this questionnaire?

Summary

In recent years, firms have increasingly relied on external knowledge as a source of competitive advantage, which has increased the tendency of firms to establish relationships with universities. At the same time, universities are motivated to develop closer relationships with firms in order to get access to research funds and firms' resources. There are different ways in which universities and industry can collaborate with each other, such as contract research, collaborative research, patenting, and licensing. In this study we consider one of the promising ways of collaboration between universities and industry, which is collaboration through Ph.D. projects. In fact, almost one third of all Ph.D. projects at the Eindhoven University of technology are collaborative projects, making it a much more frequent phenomenon than university patenting, for instance. While collaborative Ph.D. projects have a great potential for transferring knowledge from university to industry, they received very little attention in the existing literature on university– industry relations. While promising, collaborations are a resource-consuming type of relationship, in which one needs to invest time, energy and money. Therefore, it is vital for the partners to maximize the probability of successful outcomes. In a collaboration involving different organizations, success heavily depends on the governance of the collaboration. More specifically, entering into a collaboration requires making important decisions, for instance on the funding the project, its content, and the management of day-to-day relationships, all factors that may impact the success of the collaboration. Benefits of a joint research collaboration are likely to be best derived under a well-defined governance structure.

The aim of this thesis is to generate a better understanding of how universities and their collaborative partners govern their collaborative Ph.D. projects, and to what degree these choices do indeed optimize success (where success is a multidimensional

concept). Because there might also be concerns that collaborative Ph.D. projects could result in poorer academic performance compared to regular Ph.D. projects done within the university, a second aim of this thesis is to compare the scholarly outcomes of both types of projects.

For reaching these aims, this study uses two different data sets. First, original data has been collected through an extensive survey that was answered by 191 former Ph.D. candidates involved in collaborative Ph.D. projects with industry or with Public Research Organizations (PROs). This survey was used to identify the determinants of governance choices among partners, and how governance characteristics affect the success of collaboration. Furthermore, bibliometric performance data was constructed from 224 doctoral candidates involved in collaborative projects, as well as from a matching set of 224 peers that did regular (non-collaborative) Ph.D.s.

The major findings of this study are as follows. We found that when there is high level of geographical and/or cognitive proximity between the partners, the active involvement of both in management and decision-making (shared governance) becomes more likely. In turn, such a shared governance was found to be one of the strongest factors that positively influences success. Other factors with a positive influence are previous collaboration experience and frequent communication between the Ph.D. candidate and its industry supervisor. Finally, the bibliometric data on comparing the outcomes of collaborative Ph.D. projects with regular Ph.D. projects showed that doctoral researchers that did a collaborative Ph.D. project have better academic performance than their non-collaborative peers, with respect to both quality and quantity criteria. The same holds for patenting, both in terms of number of patents and the impact of these patents.

About the author

Negin Salimi was born on February 4, 1983 in Tehran, Iran. In 2005, she received her Bachelor of Science in Industrial Management (with honours), and received her master degree in Management of Technology (with honours) from University of Allameh (UA), Tehran, Iran in 2008. Her master thesis focused on innovation systems. She won the best national dissertation award for her M.Sc. in Management of Technology in 2010. In July 2010, she started her Ph.D. at the School of Innovation Sciences at Eindhoven University of Technology, where she developed several theoretical approaches to collaboration between universities and industry through Ph.D. projects, a theoretical model to study the governance and success of collaborative Ph.D. projects, and where she applied several statistical methodologies to investigate and validate the proposed theoretical models. She has presented her research at several international conferences and workshops, and has published in peer-reviewed journals. Additionally, she was involved in co-organizing the IEEE International Technology Management Conference & 19th ICE Conference, in 2013, The Hague, The Netherlands. Her research interests cover university-industry relationships, knowledge management, innovation management, and responsible innovation. Negin is currently employed as postdoctoral researcher at Delft University of Technology, The Netherlands where she works on responsible innovation.

List of publications

Journal Papers

Salimi, N., Bekkers, R., Frenken, K. (2014). Governance Mode choice in Collaborative Ph.D. projects. *The Journal of Technology Transfer*, DOI: 10.1007/s10961-014-9368-5.

Rezaei, J., Salimi, N. (2013). Optimal ABC Inventory Classification using Interval Programming. *International Journal Systems Science*, In press.

Rezaei, J., Salimi, N. (2012). Economic order quantity and purchasing price for items with imperfect quality when inspection shifts from buyer to supplier. *International Journal of Production Economics*, 137(1), 11-18.

Under review

Salimi, N., Bekkers, R., Frenken, K. Does working with industry come at a price? A study of doctoral candidates' performance in collaborative vs. non-collaborative Ph.D. projects. *Technovation*, Submitted May 2014 (now in the second round of review).

Salimi, N., Rezaei, J. A multi-Criteria Approach to University Selection by Firms. *Journal of Systems Science and Systems Engineering*, Submitted February 2014.

Salimi, N., Bekkers, R., Frenken, K. Governance and success of university-industry collaborations on the basis of Ph. D. projects: an explorative study. *Research Policy,* Submitted April 2013 (now in the second round of review).

Conference Papers

Salimi, N., Bekkers, R., Frenken, K. (2014). Does working with industry come at a price? A study of doctoral candidates' performance in collaborative vs. non-collaborative Ph.D. projects. *15th International Schumpeter Society Conference,* July 27-30, 2014, Jena, Germany.

Salimi, N., Bekkers, R., Frenken, K. (2014). Distributed or Localized Mode of Governance in Collaborative PhD Project: the Effect of Proximities and Resource Imbalances. *Geography of Innovation Conference*, January 23-25, 2014, Utrecht, The Netherlands.

Salimi, N., and Rezaei, J. (2013). University Relationship Management: An Introductory Overview. *19th IEEE & ICE-ITMC International conference on Technology and Innovation Management*, June 24-26, 2013, Den Haag, The Netherlands.