How firms collaborate with public research organizations: the evolution of proximity dimensions in successful innovation projects

Abstract

Although public research organizations (PROs) are potentially valuable collaboration partners for firms in the development of innovations, most firms find it difficult to develop and sustain fruitful collaborations with PROs. Proximity dimensions, such as geographical, cognitive, organizational, and social proximity, are important facilitators of inter-organizational collaboration. Nevertheless, our understanding of the interaction between and evolution of different proximity dimensions over time is limited. Based on a longitudinal study of 15 successful innovation projects involving firms and PROs as collaboration partners, we find that different proximity dimensions are important for the establishment of new collaborations, depending on a firm's characteristics. While engineering-based firms tend to rely on geographical and social proximity to PROs, science-based firms rely more heavily on cognitive and organizational proximity. Moreover, we observe that firms with initial social and geographical proximity to PROs can sustain and expand their collaborations by developing cognitive and organizational proximity over time.

Key words: Engineering-based firms, Innovation projects, Proximity dimensions, Public research organizations, Science-based firms, Universities

JEL Classification: O32

1. Introduction

Although most firms recognize that they must develop new or improved products, services, and processes to remain competitive, innovation is a difficult task

(Katila and Ahuja, 2002). Indeed, many firms struggle to develop innovations that extend beyond their existing knowledge, technology, and competences (Stuart and Podolny, 1996). External knowledge sources are thus an important supplement to firms' internal knowledge bases and are often critical to the development of innovations. Hence, different types of alliances, partnerships and collaborations can play a crucial role in improving firms' innovation performance (Nieto and Santamaria, 2007). Our understanding of how companies can access, use, and manage external knowledge successfully in their innovation processes is nevertheless underdeveloped.

An important external source of knowledge in the development of innovations is universities and other public research organizations (henceforth PROs). PROs play a crucial role in R&D and innovation across a wide range of industries (Cohen et al., 2002), and the importance of PROs as a source of external knowledge is increasingly emphasized in the literature (Fabrizio, 2009). The role of university-industry links in innovation has been extensively studied, but the organizational dynamics underlying these relationships are not well understood (Perkmann and Walsh, 2007).

In this paper, we examine how firms can establish and sustain collaborations with PROs in the development of innovations. Although PROs and universities are a potentially valuable source of new knowledge, absorbing this knowledge is challenging for firms (Cohen and Levinthal, 1990), as evidenced by the many unsuccessful attempts at knowledge transfer between universities and firms (Santoro and Bierly, 2006). The challenge of such knowledge transfer often relates to the development of trust and the establishment of a common understanding in communications and interactions between firms and academics. An emerging body of literature indicates that different dimensions of proximity play an important role in explaining inter-organizational collaborations (Knoben and Oerlemans, 2006) and facilitating interactions between firms and academia (Boschma, 2005, D'Este et al., 2012).

In particular, the literature describes the dimensions of proximity that facilitate the formation of collaborations, whereas less attention has been given to the interplay and evolution of different dimensions of proximity over time (Balland et al., 2014, Mattes, 2012). Hence, we pose the following research question: *How do different dimensions of proximity facilitate successful collaborations between firms and PROs, and how do these dimensions evolve over time?*

The literature on inter-organizational knowledge transfer is dominated by quantitative studies, which are often based on data from single informants representing one partner in an alliance relationship (Meier, 2011). Hence, we have extensive knowledge about the characteristics of successful collaborations, but the development process of such collaborations and the underlying mechanisms and processes of collaboration remain largely unexplored (Balland, 2011). Differences in firm characteristics and knowledge bases likely influence the role of different combinations of proximity dimensions (Mattes, 2012). We focus on two types of firms, science-based firms and engineering-based firms (Autio, 1997), to examine whether these two groups of firms benefit from different combinations of proximity dimensions to establish and sustain successful collaborations with PROs. This study builds on data uncovering the history of 15 successful technological innovation projects conducted by firms of varying size and age.

Our paper makes several contributions to the literature. Most prior research on the role of proximity in inter-organizational collaborations has been cross-sectional and quantitative in nature and has examined the factors that lead to the establishment of collaborations. By contrast, our in-depth qualitative study considers the development process of successful collaborations and thus reveals how collaborations emerge and evolve over time. Moreover, by using innovation projects rather than firms as the unit of analysis, we obtain more precise information on specific collaborations. Firm-level studies overlook the fact that the same firm may have both successful and unsuccessful innovation projects involving a variety of collaboration partners, and they may therefore miss important dynamics in the collaborations. By differentiating between science-based and engineering-based firms, we show that the role of proximity in innovation depends on contextual factors.

In particular, we extend research on proximity by noting the important role of social and geographical proximity in firms' ability to establish collaborations with external partners that are cognitively and organizationally distant. Moreover, we show how firms actively build successful collaboration by becoming more proximate to PROs on the cognitive and social dimensions. Our research thus contributes to a more precise understanding of how different dimensions of proximity are related, how they develop over time, and under what conditions the proximity dimensions facilitate collaboration projects between firms and PROs to develop innovations.

The paper is organized as follows: Section 2 outlines our theoretical framework. Section 3 presents the methodological approach. Section 4 presents our findings and propositions. Finally, Section 5 contains our conclusions and the implications of our research for further research and practice.

2. Theoretical Framework

2.1. Firm-PRO collaboration for innovation

Firms that seek to involve external actors in their innovation processes face the paradox that the types of actors that are likely to provide the most complementary knowledge are also the most challenging actors to work with. Collaborations between firms and PROs illustrate this paradox. On the one hand, PROs are valuable collaboration partners, and firms that collaborate with PROs are more likely to develop innovations than other firms (Howells et al., 2012). PROs possess technological expertise and knowledge that can be a valuable input in firms' innovation processes. In particular, PROs can facilitate organizational learning and new knowledge creation (Hardy et al., 2003). On the other hand, most firms find it difficult to collaborate with PROs, particularly universities. Business organizations and PROs pursue different goals; therefore, they are structurally different from each other in many ways, such as in their incentive structures and management styles. Various orientation- and transaction-related barriers thus impede firm-PRO collaboration (Bruneel et al., 2010). These differences often prevent firms from using PROs as sources of external information in the innovation process, and firms generally rate PROs very low as information sources and potential partners (Howells et al., 2012).

The ability to use external actors in the innovation process has been linked to a firm's absorptive capacity, which is defined as "the ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990). A key feature of the absorptive capacity perspective is that collaboration with external actors depends on the level of prior related knowledge between the firm and the collaboration partner. A firm's absorptive capacity is thus higher when its partners are similar and when they possess similar knowledge bases (Luo and Deng, 2009). Although firms are better able to collaborate if their partners are similar, partners that are too similar may not be able to provide resources and knowledge that are sufficiently heterogeneous to facilitate the development of innovations (Nooteboom et al., 2007).

2.2. The proximity perspective

To better understand how firms can accumulate knowledge from collaborative PROs, we rely on the proximity perspective. The proximity literature has developed a fine-grained framework for understanding different aspects of inter-organizational collaboration, suggesting that different dimensions of proximity can facilitate successful inter-organizational collaboration (Knoben and Oerlemans, 2006, Boschma, 2005). Proximity is an important condition for collaborative innovation performance, and different proximity dimensions contribute to firm-PRO interaction and knowledge transfer in different ways (Boschma, 2005). To understand the factors behind the process of interaction and knowledge transfer, proximity is crucial because it promotes trust and understanding in complex and high-risk innovation projects (Menzel, 2008). The literature offers many different dimensions of proximity that may affect collaboration and innovation (Boschma, 2005). Our focus is in line with Broekel and Boschma (2012), who examines the role of geographical, cognitive, social, and organizational proximity in innovation performance.

Geographical proximity refers to territorial or spatial proximity (Broekel and Boschma, 2012), and it promotes knowledge transfer and innovation because it facilitates face-to-face interactions among collaborative partners (Knoben and Oerlemans, 2006). Research has well established that firms tend to collaborate with geographically close universities and PROs (Slavtchev, 2013). A study of university-industry collaborations suggests that geographically proximate links are more likely to facilitate innovation and learning effects within firms (Broström, 2010). Moreover, geographically proximate interaction is related to successful R&D projects with short times to market, whereas such interaction is generally considered less critical for long-term R&D projects (Broström, 2010).

Cognitive proximity refers to similarities in the way that actors perceive, interpret, understand, and evaluate the world (Nooteboom et al., 2007). To communicate and transfer knowledge effectively, actors require similar frames of reference (Knoben and Oerlemans, 2006). Firms must have comparable knowledge bases to be able to recognize the opportunities created by collaboration but must have fairly diverse specialized knowledge bases to utilize that knowledge effectively and creatively (Colombo, 2003). Partners' technological relatedness has an inverted U-shaped relationship with innovation value in the context of university-industry collaborations (Petruzzelli, 2011).

Organizational proximity refers to shared relations within or between organizations, and it is advantageous for innovation networks (Boschma, 2005). This dimension of proximity is supported by common rules and routines in organizations (Torre and Rallet, 2005). Arguably, significant organizational distance exists between industrial firms and PROs. Firms and PROs have different purposes and experiences, and considerable tension may exist between academic and commercial orientations. Organizational proximity is known as closeness among firms within the same corporate group (Boschma, 2005). When the level of organizational proximity is high, organizations are more likely to interact (D`Este et al., 2012).

Social proximity refers to actors that belong to the same space of relations (Knoben and Oerlemans, 2006). When firms are socially embedded, the likelihood of interactive learning and innovation increases (Boschma, 2005). Relations between actors are socially constructed when they involve trust, friendship, kinship, and common experience (Boschma, 2005). This dimension of proximity, which is often strengthened though past collaborations and repeated contacts between partners that generate reputation and trust (Balland, 2011), increases the probability that firms engage in innovative networks (Boschma, 2005).

2.3. Strengths, weaknesses, and interplay of different dimensions of proximity

The different dimensions of proximity are considered drivers of learning and innovation (Boschma, 2005, Balland, 2011) because they emphasize the advantages of being geographically, cognitively, organizationally, and socially proximate to collaborative partners. However, some studies have noted disadvantages associated with proximity, as excessive proximity may undermine learning and innovation (Boschma, 2005, Cassi and Plunket, 2013a). The proximity concept allows for alternative ways to reach the same outcome, and it is well suited to the study of qualitative changes in relationships between collaborative partners over time. Different dimensions of proximity may be important depending on the characteristics of the firm and the type and phase of the innovation project. Moreover, one dimension of proximity may substitute for another, whereas other dimensions may complement each other. Recent studies have also begun to explore the interplay between different types of proximity (Huber, 2011, Menzel, 2008). Table 1 summarizes the four dimensions of proximity, their strengths, their weaknesses, and the interplay between them.

Table 1. Strengths, weaknesses, and interplay of different dimensions of proximity

Proximity	Strengths	Weaknesses	Interplay
Geo-graphical	• Brings people together and makes knowledge transfer easier (Boschma, 2005). • Firms proximate to knowledge sources show higher innovative performance (Audretsch and Feldman, 1996). • Has a positive impact on the establishment of collaboration because frequent interaction enables firms to spend resources on more complex learning processes (Cassi and Plunket, 2013a).	• Proximate partners can be a source of mistrust because they feel threatened in local markets (Ben Letaifa and Rabeau, 2013). • Plays a role in the establishment of collaboration but a minor role in subsequent collaborations (Cassi and Plunket, 2013a). • Too much geographical proximity may weaken innovative performance and impede responses to new developments (Boschma, 2005).	• May play a role in building social, organizational, institutional, and cognitive proximity (Boschma, 2005). • Is more important when firms lack social proximity (Cassi and Plunket, 2013b). • Geographical proximity overlaps with cognitive distance for young firms with low levels of technological knowledge (Broekel and Boschma, 2011).
Cognitive	• Facilitates effective communication (Boschma, 2005). • People with a shared knowledge base may learn effectively from each other (Nooteboom, 2000). • Similar technical language is important for innovation (Huber, 2011).	• Too much cognitive proximity may weaken learning and innovation, as interactive learning requires complimentary knowledge (Boschma, 2005). • A high level of cognitive proximity may hinder firms' ability to exploit new knowledge, as they are often in the same paradigm (Nooteboom, 2000).	• Cognitive proximity and geographical proximity may be complementary for smaller (not younger) firms (Broekel and Boschma, 2011).
Organi-zational	• Closer connection between firms fosters collaboration and knowledge spill-over (Balland, 2011). • Firms' knowledge bases are more readily available to collaborative partners (Balland, 2011). • Has a positive effect on establishing collaboration (Cassi and Plunket, 2013a).	• Too much organizational proximity may undermine learning and innovation because of a lack of flexibility (Boschma, 2005). • Poses a risk of being closed to specific relationships, which may hinder access to other sources of useful information (Boschma, 2005). • Interactive learning is rare in bureaucratic systems (Boschma, 2005).	• Can often be leveraged with social proximity (Ben Letaifa and Rabeau, 2013). • Firms can compensate through organizational proximity when they lack cognitive or social proximity (Cassi and Plunket, 2013b).
Social	• Socially embedded firms foster interactive learning and innovation (Boschma, 2005). • Facilitates the trust needed for effective collaboration (Boschma and Frenken, 2009). • Social proximity makes communication and collaboration easier, as trust and mutual commitment are built when people know each other (Ben Letaifa and Rabeau, 2013).	• Too much social proximity may lead to deception because of closed communities between people (Ben Letaifa and Rabeau, 2013). • Creates the risk of opportunistic behavior, as overly close social relationships may produce negative results for calculating actors (Boschma, 2005). • May lock out other outsiders with new ideas from close social networks (Boschma, 2005).	• Geographical and organizational proximity determine the establishment of collaboration. Social proximity can act as a substitute for these proximity dimensions in further collaborations (Cassi and Plunket, 2013b). • Social proximity overlaps with the need for geographical and organizational proximity (Cassi and Plunket, 2013b).

Different dimensions of proximity clearly enable effective collaboration between firms and PROs. However, the role of different proximity dimensions in such collaboration is likely to depend on firm characteristics, such as a firm's knowledge base (Mattes, 2012). For instance, geographical proximity is more important for collaborations between academic and non-academic organizations than for those between purely academic collaborators (Ponds et al., 2007). Moreover, the role of geographical proximity in university-industry interactions is more important for less R&D intensive firms, whereas more R&D intensive firms tend to collaborate with top-tier universities, irrespective of geographical distance (Laursen et al., 2010). Further, collaborations between researchers and large firms tend to occur over larger geographical distances than collaborations with small firms (Slavtchev, 2013). Hence, we suggest that the combinations of proximity dimensions required to collaborate successfully with PROs are contingent on firm characteristics.

2.4. Firm categorization and proximity

Firms have been categorized in many different ways (e.g. Beise and Stahl, 1999, Pavitt, 1984, Castellacci, 2008). To examine how firms innovate, distinguishing between science-based and engineering-based firms might be useful (Autio, 1997). Science-based firms tend to be technology driven, whereas engineering-based firms tend to be market driven (Chidamber et al., 1994). Science-based firms mostly exploit scientific breakthroughs and tend to be more R&D intensive, whereas engineering-based firms exploit market opportunities and tend to access external knowledge from within the industry (Autio, 1997). These two types of firms likely rely on different knowledge bases for learning and knowledge accumulation. A common conceptualization distinguishes between three different types of knowledge bases: synthetic, analytical, and symbolic (Asheim and Gertler, 2005, Asheim et al., 2007, Moodysson et al., 2008). In this paper, we focuses on synthetic and symbolic knowledge bases because we study technological innovation projects, and we exclude the symbolic category because it is primarily related to cultural and creative industries (Asheim et al., 2007).

Science-based firms primarily have analytical knowledge bases in which scientific knowledge is highly important and in which the creation of knowledge is based on cognitive and rational processes, such as that in biotech or infrastructure technology. Engineering-based firms primarily have synthetic knowledge bases in which innovations are created in industrial settings through the transfer of existing knowledge to generate new knowledge combinations. Innovations in engineering-based firms typically solve specific practical challenges, for example, those related to plant engineering and industrial machinery (Asheim and Coenen, 2005). Science-based firms have more frequent university-industry links than engineering-based firms, in which R&D is less important (Asheim and Coenen, 2005).

Regardless of the differences in their knowledge bases, collaborating with partners possessing similar technological capabilities and having expertise in the same field appears to be beneficial for both types of firms to achieve learning and to accumulate knowledge (Colombo, 2003). Mattes (2011) further emphasizes that firms with different knowledge bases require different dimensions of proximity to achieve learning and accumulate knowledge. For instance, some degree of cognitive proximity is fundamental for the transfer of both synthetic and analytical knowledge bases. Moreover, geographical and social proximity is important for the transfer of synthetic knowledge bases but is less important for analytical knowledge bases, as such knowledge requires the transfer of largely codified knowledge.

Presumably, science-based firms rely on different combinations of proximity dimensions when they collaborate with PROs compared with engineering-based firms, which are less familiar with R&D. For instance, the high R&D intensity among science-based firms will likely strengthen their absorptive capacity, which makes them less dependent than engineering-based firms on geographical proximity

(Laursen et al., 2010). Science-based firms also tend to have stronger social ties with PROs (Balland, 2011) and similar frames of reference (Knoben and Oerlemans, 2006); therefore, they are likely to be more socially and cognitively proximate to PROs at the outset of collaboration projects. Because of their market orientation and lower R&D intensity, engineering-based firms are likely to have lower cognitive, organizational, and social proximity to PROs; hence, they must build upon other combinations of proximity dimensions to successfully collaborate with PROs. Our study explores the combinations of proximity dimensions used by science-based and engineering-based firms to successfully collaborate with PROs over time.

3. Methodology

3.1. Research design

We use a sample of 15 top-performing innovation projects to uncover the patterns of collaboration that lead to successful innovations. A case-study design was chosen to examine how the firms were able to collaborate successfully with PROs over time (Eisenhardt, 1989). This approach allows for richer contextual insight and a more in-depth understanding of a process that has received little attention in prior studies. Multiple-case studies provide a stronger base for theory construction than single-case studies (Yin, 1989), as the emergent findings can be compared across cases and as the findings may be grounded by varied empirical evidence (Eisenhardt and Graebner, 2007). Further, the use of comparative case studies is appropriate to gain new insights into organizational phenomena over time (Eisenhardt, 1989).

3.2. Case selection

The sample is drawn from a public support scheme that supports high-potential user-driven innovation projects in Norwegian industry (the Research Council of

Norway's BIP-program). We selected 15 projects from a population of 709 projects that received public support during the period from 1996 to 2005. Each project was managed by a lead firm and included PROs and occasionally other firms as partners. The 15 projects were among the top-performing projects measured in terms of their contribution to profit as reported by the firms three years after project completion. Following Yin (1989), we selected a sample representing a variety of different contexts by including firms that vary in size from small start-ups to large industrial firms. Moreover, the firms varied in their R&D experience and connections to PROs, and they could be classified as either science-based or engineering-based firms (Autio, 1997), as shown in Table 2.

Table 2 Classification of science-based and engineering-based firms at project start

Case	Type of firm (size* and industry)	Exploitation of technology (Autio, 1997)	Motivation of technology (Chidamber et al., 1994)	R&D ties (Asheim and Coenen, 2005, Arrow, 1994)	R&D orientation (Autio, 1997)
1	Science-based (Small biotech)	Exploiting scientific breakthroughs	Technology-driven	Connections with several universities and R&D organizations	R&D is a key part of the firm's operations. Long experience with internal R&D
2	Science-based (Micro ICT)	Exploiting scientific breakthroughs	Technology-driven	Firm established by researcher; several researchers are part of firm management	R&D is primary activity of the firm. Close relationships with academic researchers
3	Science-based (Small science)	Testing of a basic scientific patent	Technology-driven (lack of market motivation)	Strong connection with a research institute	R&D is primary activity of the firm. Firm established by researcher
4	Science-based (Large science)	Technological opportunity	Technology-driven	Established a new relationship with another research institute as part of the project	R&D is a key part of the firm's operations. The firm spun off from research institute
5	Science-based (Micro biotech)	Spun-off basic research	Technology-driven	Firm spun off from university and maintains strong connections	R&D is primary activity of the firm. Close relationships with academic researchers
6	Engineering-based (Large process industry)	Exploiting market opportunity	Market-driven	Several connections with national and international universities and R&D organizations	Own R&D department. Long experience with R&D
7	Engineering-based (Small engineering)	Market opportunity	Market-driven	Limited use of research organizations for this project	Internal R&D. Strong knowledge of prior R&D projects
8	Engineering-based (Large process industry)	Market opportunity	Market-driven	Strong connection with a research institute	Own R&D department. Long experience with R&D
9	Engineering-based (Large process industry)	Market opportunity	Market-driven	Strong connection with a research institute and university	Internal R&D team. Long experience with R&D
10	Engineering-based (Micro engineering)	Technological opportunity	Technology-driven	Several connections with research organizations	Own R&D department. Experience with similar projects
11	Engineering-based (Large engineering)	Technological opportunity	Market-driven	Firm spun off from a research institute and has a strong relationship with a university department	Internal R&D team. Ongoing R&D activities
12	Engineering-based (Medium engineering)	Market opportunity	Market-driven	Existing relationship with a research organization	Internal R&D team. Low R&D experience, but intention to increase R&D activity
13	Engineering-based (Large engineering)	Market opportunity	Market-driven	Strong connection with a research institute	R&D is a key part of the firm's operations. R&D important in building the firm
14	Engineering-based (Large process industry)	Market opportunity	Market-driven	Connections with several organizations	R&D team with internal and external members. R&D is important in building the firm.
15	Network, several engineering-based firms (varying size)	Implementing new technology	Technology-driven	Research institute plays key role in planning and conducting the project	Several smaller projects conducted by different partners. Project initiated by a public research institute

*EU's categories for firm sizes are used: large > 250, medium < 250, small < 50, and micro < 10 employees.

3.3. Data collection

Archival data regarding the pre-start-up and start-up activities of innovation projects are rarely available. Because all projects in our study were part of a public support program, we were able to obtain similar information about all the cases. Our data include archival material, such as the initial project description, the final report, and the assessment of the R&D program, and survey responses from the firm at the start of the project period, the end of the project period, and three years after the end of the project. In addition, relevant written documentation was collected from press articles, web pages, and other sources.

Furthermore, we interviewed, on average, three key persons who were involved in each project, including representatives of both the firms and the PROs (Table 3). These interviews enabled us to gain a thorough understanding of how the innovation process unfolded in each case, including interactions between the project and the firm levels. Multiple informants and archival material were used to increase the validity of the retrospective accounts (Miller et al., 1997). In total, we conducted face-to-face interviews with 32 persons and telephone interviews with 8 persons.

Table 3 Number of key data sources and interviews for each case

Case		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Sum
Secondary sources	Project description	1	1	1	1	1	1	1	1	1	1	1	1	1	na	1	14
	Final reports	1	1	1	1	1	1	1	1	1	1	1	1	1	na	1	14
Interviews	Project manager at the firm	1	1	1	1	1	1	1	1*	1	1	1	1	1	1	1*	15
	Firm researcher	1			1	1		1	1		1	2	1			3*	12
	PRO project manager				1				1	1		1	1	1		1*	7
	PRO researcher			1	1*			1*	1	1	1						6
	Total number of interviews	2	1	2	4	2	1	3	4	3	3	4	3	2	1	5	40

na = not available, *phone interview

To obtain an in-depth understanding of how the innovation process unfolded in each project, the informants were asked to describe the process from inception to the present with minimal interruption by the interviewers. The interview template was designed to reveal the history of a project in chronological order, starting with the background for the initiation of the innovation project, continuing with the planning of the project, proceeding to the execution of the project, and ending with the results achieved by the project. To gain detailed information on the critical events and actors in the process, we used open-ended follow-up questions such as “Why did you do that?” “Who was involved in this event?” “When did this happen?” We focused on facts and concrete events to avoid cognitive biases and impression management (Miller et al., 1997). Moreover, to avoid potential bias, the theoretical concepts used in this paper were not explicitly referenced by the interviewers.

3.4. Data analysis

The collected data provided both narrative accounts of the process (Pentland, 1999) and factual descriptions of the context, actors, and events from a large number of sources. Although the extensive documentation for each project provided additional information, we found that the retrospective interviews gave accurate information about the project histories (Miller et al., 1997). The interviews were recorded and transcribed by the authors as part of the data analysis process. Based on the interviews and available documents, we wrote case descriptions for each of the projects, and the project managers verified these case descriptions as a validity check. The data analysis was based on a triangulation of data sources for each case, followed by cross-case comparisons. From the analysis, we were able to obtain a comprehensive picture of how the project and firm levels interacted with the external collaboration partners. To derive theoretical explanations of the observed processes, we identified observations that matched the theoretical concepts (Orton, 1997). To avoid conflating multiple levels of analysis, a strategy of retroduction was used (Downward and Mearman, 2007). Thus, as the analysis proceeded, the overarching logical frame shifted from data exploration to model construction to the empirical scrutiny of the models derived (Van de Ven and Poole, 2002).

4. Results and Discussion

4.1. PRO collaboration and the role of proximity

The firms in our study collaborated with PROs in innovation projects to create new products, processes, or organizational innovations. The motivation behind the PRO collaboration was to gain access to new complementary knowledge for the project (Brockhoff et al., 1991), as illustrated by one project manager describing the PRO partner: "*We could not succeed without them. We did not have enough knowledge in our R&D department or in the company to succeed with this project.*"

In our analysis, we distinguish between science-based firms and engineering-based firms (Autio, 1997). Although substantial heterogeneity exists within each of these groups, the five science-based firms in our sample are highly familiar with academic research (see Table 2). They share social ties, a common language, and technological knowledge with the collaborative PROs. The ten engineering-based firms in the sample are less research intensive than the science-based firms; they have fewer social ties with PROs and do not have the same level of shared common language and technological knowledge in their projects. Because of the relatively lower levels of internal research activities for engineering-based firms (Cohen and Levinthal, 1990), these firms appear to require different types of proximity from science-based firms to achieve successful collaboration with PROs (Mattes, 2012).

Table 4 briefly describes the relationships between the firms and PRO partners within each innovation project in terms of cognitive, organizational, social, and geographical proximity at project start. As Table 4 illustrates, the proximity dimensions of engineering-based and science-based firms differ at project start. Nevertheless, all the firms had successful innovation projects in collaboration with PROs. As our analysis progressed, we observed that the combinations of proximity dimensions that are necessary to establish collaborations differ from the combinations of proximity dimensions that are necessary to sustain successful collaborations over time.

Based on our analysis, we propose that the evolution and interplay of proximity dimensions over time played a key role in the success of collaborations. Figure 1 illustrates the importance of different proximity dimensions and the interplay between and evolution of these dimensions for science-based and engineering-based firms. The arrows illustrate the interplay between different proximity dimensions over time, and the importance of each proximity dimension is indicated by the size of each box. Note that the size of each box illustrates the proximity dimension's relative importance for PRO collaboration; it is not an attempt to capture the actual level of proximity.

Table 4 Overview of proximity dimensions between firms and collaborating PROs at project start

Case firm	Geographical proximity	Social proximity	Cognitive proximity	Organizational proximity
1 Science-based	Used different national and international PROs that were geographically distant	Not important for establishing collaboration with PRO partners	Had significant R&D experience (including PhD) and technological similarities to PROs	Organized as an R&D firm with similar functions as PROs
2 Science-based	Primary PRO partners located in the same city, some international collaborations	Founders were previously employed by the PRO partner	Had significant R&D experience and technological similarities to PROs	Organized as an R&D firm with an integrated team of PRO and company employees
3 Science-based	Close collaboration with PRO partner in another city International partner added in subsequent project	Company founder and PRO researcher were previous classmates or colleagues	Had R&D experience (including a PhD) and similar competence as a PRO partner	Was a very small firm that collaborated in close interaction with a PRO
4 Science-based	Two PRO partners located in same region	No prior relationship with the primary PRO partner; founders were previously employed by the other PRO partner	Had significant R&D experience, but the primary PRO partner was within different research area; PRO employees were later recruited as firm employees	R&D was the primary activity of the firm; developed a service in this project that was commercialized jointly with the PRO
5 Science-based	International PRO partner	One of the firm founders had a good relationship with the PRO partner	Research-based firm within the same subject area as the PRO partner	R&D was the primary activity of the firm; differences existed in the organizational structure between countries
6 Engineering-based	Several national and international PRO partners with different locations	All PROs, except international ones, were known partners from prior projects	Had significant R&D experience in their own R&D department and PRO partners had competence in different areas	The firm's R&D department collaborated closely with PRO partners
7 Engineering-based	PRO partners in different locations; little use of PRO partners in this project	Firm project manager had been involved in prior research at the PRO; no relationship with a PRO partner in this project	Limited collaboration experience with PROs	Had a more development-oriented focus compared to PRO partners
8 Engineering-based	PRO partners at different locations	Long-standing close relationships with PROs	Firm had strategically developed relevant competence in PRO partners. Several examples of mobility between firm and PROs	Highly integrated teams of PRO and firm employees worked closely together
9 Engineering-based	First PROs were located in same area and other cities; later PRO partners were more distant (international)	High level of acquaintance with PROs; project leader at PRO partner was a former employee at the firm	High level of joint R&D experience between the firm and PRO based on prior collaboration on similar topics	Dedicated employees in the firm worked with PRO partners on the project
10 Engineering-based	The firm's R&D department at two locations collaborated with PRO partners located at the same locations	Some prior relationships with all PRO partners	Some R&D experience from prior projects; a firm employee had completed a PhD at the PRO partner	The firm had its own R&D department
11 Engineering-based	The firm and PROs were located in same area	The PRO partners were all well acquainted from prior collaborations	Long tradition of R&D collaboration with PROs; employee had started a PhD program in a prior project	The firm had an R&D department, but had a more development-oriented focus compared to PRO partners
12 Engineering-based	The firm and PROs were located in same area	Firm project manager had been previously employed at the PRO partner	The firm had little R&D experience, but developed a common understanding during the project	Initially limited internal R&D activity; more developed during the project
13 Engineering-based	The firm and PRO were located in same area	Prior collaboration with key researcher at the PRO	Some R&D experience from developing the firm's main product	The firm used the PRO instead of building their own R&D department

14 Engineering-based	Significant geographical distance from all PROs	PRO partners were unfamiliar to the firm	Firm had limited R&D experience, but this project was important for developing R&D activity	The firm did not have an internal R&D department
15 Network of engineering-based firms	PRO partners at several different locations	Prior working relationships among several project partners	Technological similarities and common language between some project partners, but not all	Few organizational linkages between the firm and project partners

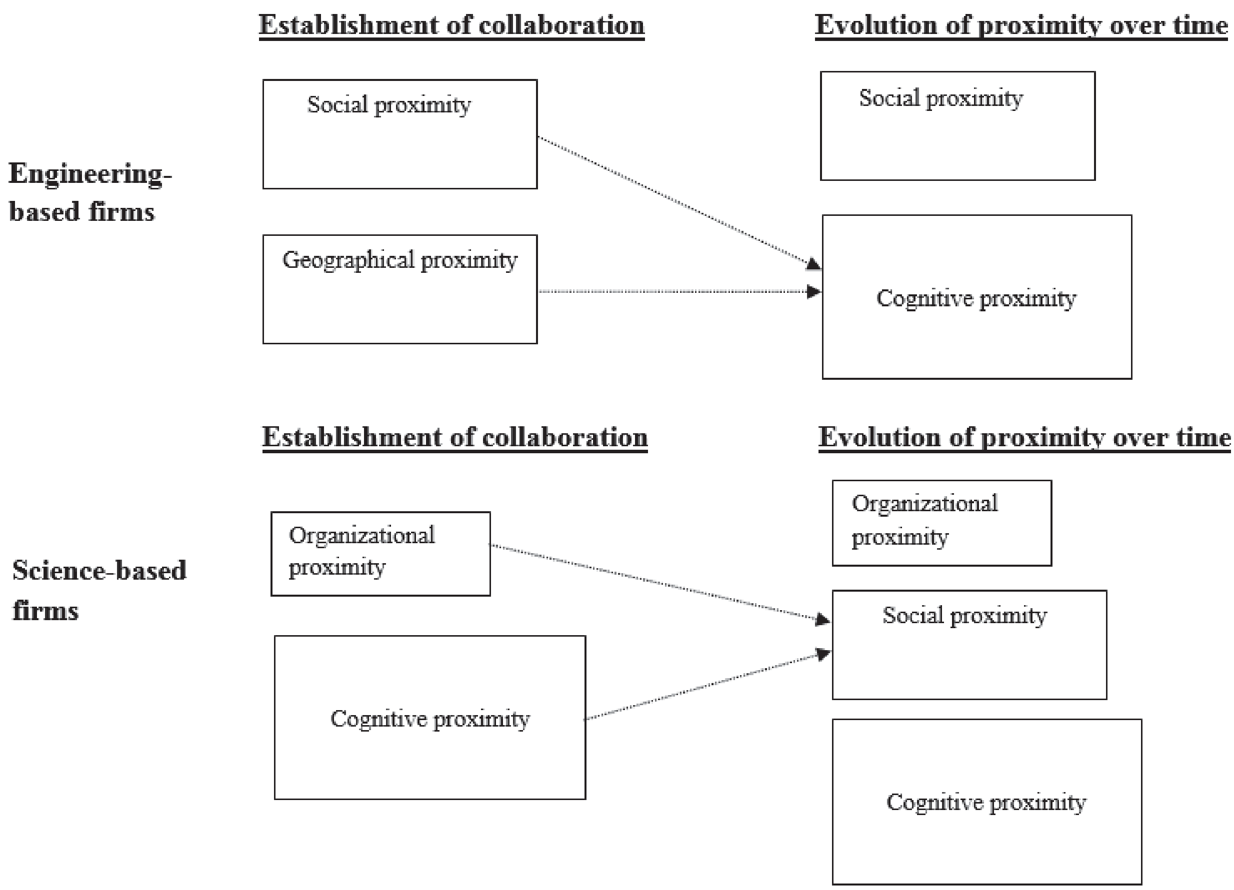

Figure 1. The establishment, evolution, and interplay of proximity dimensions for science-based and engineering-based firms

In the following sections, we first present the key findings of our study regarding the role of proximity dimensions for the establishment of collaborations; we then discuss the evolution and interplay of proximity dimensions over time with reference to Figure 1. In the discussion below, we integrate the case findings with the scholarly literature and develop propositions to clarify our theoretical arguments.

4.2. Proximity dimensions and the establishment of collaboration

Our findings indicate that the role of geographical proximity depends on firm characteristics (Laursen et al., 2010). Science-based firms tend to collaborate with PROs regardless of geographical distance, provided that the collaborative partners possess relevant expertise and knowledge that complement firms' innovation activities. As stated by one PRO researcher, *"The physical contact between the project participants is very good, despite the fact that everyone works in different locations. I had more contact with those I worked with in this project than with many of my colleagues here (at the research institute)."* Our findings confirm that engineering-based firms rely on local partners when they establish research collaborations (Asheim and Coenen, 2005). Hence, for engineering-based firms, geographical proximity to the PROs is a clear advantage because it facilitates face-to-face interaction and helps them overcome challenges related to a lack of common understanding. Engineering-based firms often find that PROs have a different agenda when they collaborate in innovation projects. For example, one firm representative observed, *"In collaboration with research organizations, we often find a difference in focus. They want to obtain further commissioned research, whereas we as a firm are interested in commercializing the technology."*

Almost all firms had prior relationships with the PRO before initiating their projects. The importance of prior contacts in the establishment of collaboration with PROs (Slavtchev, 2013) was particularly evident among the engineering-based firms. However, the science-based firms appear to have greater awareness of the value of using external R&D. These firms based their choice of collaborative research partners more on relevance than on social and geographical proximity. To quote one informant from a science-based firm, *"We collaborate with research groups and universities internationally, as they have the relevant [technological knowledge] for the further development of the technology."*

When establishing collaborations with PROs, engineering-based firms are more dependent on familiar and geographically proximate partners than science-based firms. In part, this finding confirms that social proximity overlaps with the need for organizational proximity (Cassi and Plunket, 2013b). The level of organizational proximity influences science-based firms' selection of a PRO in collaboration projects (Cassi and Plunket, 2013b). Because science-based firms often have integrated teams of academics and company employees, they have joint R&D experience with their partners, and in terms of the other dimensions, they do not require the same level of proximity that engineering-based firms need. As illustrated in Figure 1, science-based and engineering-based firms appear to depend on different dimensions of proximity to establish collaboration projects with PROs. Thus, we propose the following:

Proposition 1a: Compared with science-based firms, engineering-based firms are more dependent on social and geographical proximity to establish successful innovation projects in collaboration with PROs.

Proposition 1b: Compared with engineering-based firms, science-based firms have higher cognitive and organizational proximity with PROs and are therefore less dependent on social proximity and geographical proximity to establish successful innovation projects in collaboration with PROs.

4.3. The interplay between different types of proximity dimensions over time

We now examine the evolution of the proximity dimensions for engineering-based and science-based firms. The dynamics and interplay of proximity dimensions over time is crucial to understanding how these dimensions facilitate knowledge exchange between firms and PROs (Balland et al., 2014). Our longitudinal data show that the majority of the innovation projects in our study resulted from on prior collaborations between the firm and the primary PRO partners, led to subsequent collaboration projects, or both. Table 5 provides an overview of the firms' related R&D collaboration prior to and after the projects that were analyzed in this paper.

Table 5. The firms' related R&D collaborations with PROs before and after the projects analyzed in this paper

Case firm	Related R&D collaborations with PROs before the project	Related R&D collaborations with PROs 5-10 years after the project
1 Science-based	No R&D projects before the current project	Continued with a relatively similar R&D project
2 Science-based	No R&D projects before the current project	Participated in several R&D projects with different PROs
3 Science-based	The firm was a spin-off from the current project	Continued with several R&D projects with primarily the same PROs and some new PROs
4 Science-based	Prior R&D projects with the same PRO and with other partners	Several R&D projects with primarily the same PRO
5 Science-based	Participated in a small R&D project earlier that was a trigger for the current project	Participated in several larger R&D projects with some of the same and other PROs
6 Engineering-based	The firm's R&D department had run two preliminary projects before the current project	Several R&D projects spun out from the current project with primarily the same PROs and some new PROs
7 Engineering-based	Prior projects with other PROs	Subsequent projects with the same and other PROs
8 Engineering-based	Several prior projects with primarily the same PRO	Several subsequent R&D projects with primarily the same PROs
9 Engineering-based	Several prior projects with primarily the same PRO	Several subsequent R&D projects with primarily the same PROs
10 Engineering-based	Prior R&D projects with the same PRO and with other PRO partners	Several R&D projects with primarily the same PRO
11 Engineering-based	Prior R&D projects with a similar PRO	Several R&D projects with the same PRO and other PROs
12 Engineering-based	The firm had participated in previous product development projects, but the current project was the firm's first R&D project	The current R&D project was a trigger for several subsequent PRO collaborations
13 Engineering-based	Prior R&D projects with the same and other PROs	The firm continued with several R&D projects
14 Engineering-based	No R&D projects before the current project	No R&D projects after the current project
15 Network of engineering-based firms	Prior R&D projects with the same and other PROs	No R&D projects after the current project; the network had an R&D project accepted, but chose not to continue

For many of the firms, the innovation projects functioned as a trigger for establishing subsequent PRO collaborations. The projects that were analyzed in this study enabled several firms to develop the types of proximity that are necessary to increase the number of subsequent PRO collaborations.

Geographical proximity can be an important stimulus for firms starting projects with PROs, as geographical proximity affects the common understanding and trust between firms and partners (Boschma, 2005). As stated by one project manager from an engineering-based firm with regard to a geographically proximate PRO partner: *"We have had projects with them ever since we started developing this [technology] and before that too. That has built a mutual relationship of trust."* Collaboration with a geographically proximate PRO can then be used to develop a firm's ability to establish projects with geographically more distant PROs over time. Once contacts with local PROs are established, the firm can enter a reinforcing circle by further developing new external research contacts.

Social proximity is important for both groups of firms to sustain successful collaborations with PROs over time. Science-based firms relied on social proximity less than the engineering-based firms to establish collaborations, but over time, personal relationships appeared to be important for the success of R&D projects. Some science-based firms were very conscious of the crucial role of social proximity in the success of collaborations in common projects. These firms invested resources to achieve social proximity by visiting PROs and by becoming acquainted with potential research partners. As one representative observed, *"We travelled around [internationally] and visited relevant research partners with whom we formed collaborations."* Some of these firms also built longstanding relationships with individuals in PROs who helped them to network with other PROs. We observe that a common technological understanding (cognitive proximity) combined with a somewhat similar R&D structure (organizational proximity) enabled science-based firms to build social relations with collaborative PROs. Hence, cognitive and organizational proximity leveraged social proximity, as shown in Figure 1.

Cognitive proximity appeared to be the most important proximity dimension for both groups of firms to successfully collaborate in innovation projects over time (Nooteboom, 2000). However, cognitive proximity was achieved in different ways for the two groups of firms. Science-based firms had cognitive proximity to the PROs from the outset of projects: their research experience fostered a common understanding and good communication with their PRO collaborators. One representative of a PRO noted, *"…it is important that we academics are aware that the [industry] works under different conditions from us. On the other hand, the [industry] must understand our way of working."* Another firm representative stated, *"It is extremely important that the industry and the [PRO] clearly express our targets—where we want to go—and simultaneously give space to the involved [PROs] to create something new."*

For engineering-based firms, cognitive proximity to PROs was often lacking in innovation projects, owing to their different understandings and motivations regarding technology. As one representative of an engineering-based firm observed, *"My experience with the academic community is that they have a lot of knowledge, but the things we work with are relatively easy technologies that cannot be transferred to the "latest vogue" in research."* However, during the process of collaborating with local PROs, engineering-based firms built a common understanding with their collaborative partners. Our findings thus confirm that geographical proximity plays a role in building cognitive proximity (Boschma, 2005). Moreover, social proximity between a firm and the initial PRO partner helps firms to build cognitive proximity with PROs over time. Firms that achieve personal relations learn how to effectively communicate with PROs in general, as they become acquainted with the research "language." In this way, firms increasingly appreciate the value of R&D collaboration, and they may search for PROs independently of their geographical and social proximity to PROs the next time that they require new technological knowledge. We observed that several of the firms began to collaborate with unknown PRO partners over time (Table 5). One representative from an engineering-based firm describes the learning curve during the process of working with a PRO: *"It is not easy in day-to-day life to read heavy scientific articles you don't understand, but when working together with someone for a few years, you really understand more."* Hence, a firm can have social proximity to one PRO, but cognitive proximity is a more general type of proximity that relates to PROs more broadly.

Organizational proximity influences the evolution of collaborations over time in a manner similar to its influence on the establishment of collaborative projects. Our analysis shows that engineering-based firms may lack organizational proximity. Indeed, one of the PRO partners highlighted the challenges that arise when firms lack internal R&D activity: *"It is important for us researchers to have direct contact with someone connected to an R&D department of a firm, someone who is between us and the commercial actor. That functions very well. There have been occasions where I've been in contact with typical sales people. That has not been easy. You don't communicate very well."* For the science-based firms, organizational proximity is valuable because such firms are knowledgeable about R&D and because they can search for and collaborate with the most relevant PROs without first developing other proximity dimensions.

The engineering-based firms analyzed in this study compensated for their lack of organizational and cognitive proximity by relying on their geographical and social proximity to establish relationships with their initial collaborative partners. Gradually, as these firms learn to collaborate with PROs, they build cognitive proximity, which can then substitute for geographical proximity in subsequent research projects. Engineering-based firms often used their first PRO collaboration partner to access networks for further research collaboration and to thereby build social proximity with other research organizations. As illustrated in Figure 1, these observations lead to the following propositions:

Proposition 2a: Engineering-based firms that actively engage in R&D collaboration with socially and geographically proximate PROs are more likely to subsequently develop cognitive proximity with other PROs.

Proposition 2b: Science-based firms that actively engage in R&D collaboration with organizational and cognitively proximate PROs are more likely to subsequently develop social proximity with these PROs over time.

5. Conclusion and Implications

By focusing on the role of proximity in firms' ability to collaborate with PROs, we offer novel insights into the mechanisms underlying successful collaborations in innovation projects. As illustrated in Figure 1, we outline how different dimensions of proximity can substitute for one another, and we show that the types of proximity that facilitate collaboration depend on firms' characteristics.

5.1. Contributions

Our longitudinal data show that the combinations of proximity dimensions that are required to establish R&D projects differ from the combinations of proximity dimensions that are required to successfully collaborate in R&D projects over time. Previous research has illustrated that prior contacts (Slavtchev, 2013) and geographical proximity (Cassi and Plunket, 2013a) are important for the establishment of PRO collaborations. By distinguishing between engineering-based firms and science-based firms, our study extends these findings by showing that engineering-based firms tend to rely on prior contacts and geographical proximity to establish collaborations with PROs, whereas science-based firms tend to base the selection of their first contact on relevance rather than on social and geographical proximity. We extend previous findings suggesting that geographical distance can be overcome by organizational proximity (Capaldo and Petruzzelli, 2014) by showing how science-based firms can rely on cognitive proximity to establish R&D projects with geographically distant PROs. In addition to relevance, similar organizational structures (organizational proximity), a shared understanding, and similar technological knowledge bases (cognitive proximity) with the PRO partners are important for science-based firms to establish collaboration projects.

Further, the primary contributions of our study respond to the call for a better understanding of the evolution of proximity dimensions over time and the interplay among them (Balland et al., 2014). First, engineering-based firms build cognitive proximity over time by collaborating with familiar and geographically close PROs (Boschma, 2005), and they are dependent on social proximity to sustain successful collaboration over time. By contrast, science-based firms depend primarily on cognitive proximity and to some extent on organizational proximity, and they benefit from having R&D structures that are similar to PROs to collaborate successfully over time. Capaldo and Petruzzelli (2014) found that geographical and organizational proximity are mutual substitutes, which our results confirm in the sense that engineering-based firms and science-based firms rely on each of these types of proximity, as shown in Figure 1. Particularly interesting is the observation that science-based firms benefit from a high level of social proximity in sustaining collaboration over time but not in establishing R&D projects. Science-based firms use organizational and cognitive proximity to build this social proximity with unfamiliar partners over time. In line with Ben Letaifa and Rabeau (2013), we find that social proximity is a key factor in both engineering-based and science-based firms' ability to sustain successful collaboration over time and that this proximity cannot be substituted by other proximities.

Moreover, our study of innovation projects provides a multi-level perspective, showing that the type of proximity that is identified as important depends on the level of analysis adopted. For instance, social proximity is a key enabler of collaboration at the individual level, whereas cognitive proximity appears to be more important for maintaining long-term collaborative relationships at the organizational level. This finding indicates that engineering-based firms can develop their ability to collaborate with PROs by collaborating with socially and geographically proximate partners. Active engagement with these initial partners can then increase firms' cognitive proximity to other PROs. Hence, firms can leverage socially and geographically proximate relationships to achieve closer cognitive and organizational proximity to PROs over time.

5.2. Limitations and implications for further research

Our findings clearly illustrate that collaborations between firms and PROs are path dependent and that they often change in character over time. Hence, longitudinal studies are needed to capture the dynamic aspects of such collaborations. Because R&D collaborations frequently fail, the process of establishing a collaboration must be distinguished from the process of sustaining a successful collaboration. All of the collaborations examined by our study were successful. The inclusion of only successful collaborations, however, impedes our ability to determine whether some of the characteristics of successful collaborations also apply to unsuccessful collaborations. Future studies should therefore use long-term outcome measures and include both successful and unsuccessful collaborations to better understand the effects of different proximity dimensions.

We believe that future research can further elucidate the conceptual development of the different proximity dimensions and the relationships between them. For instance, dimensions such as social and, to some degree, cognitive proximity appear to be linked to the individual level of analysis, whereas dimensions such as geographical and organizational proximity are more closely related to the organizational level. Understanding these differences may help firms to develop and maintain fruitful collaborations with PROs and to avoid collaborations that are overly dependent on individual relationships.

5.3. Managerial implications

Most firms are not in a position to exploit the knowledge residing in universities and other PROs. However, as firms invest in internal R&D and as they increase their level of proximity with relevant collaboration partners, they can more effectively use external knowledge in innovation projects. Although firms appear to be able to compensate for a lack of proximity to alliance partners through better resource allocation (Simonin, 1999), such compensation may be a very costly in the absence of further guidance on how to work with PROs. This study has identified potential pathways through which firms can successfully collaborate with PROs in developing innovations. Our study shows that firms can rely on different dimensions of proximity to PROs in order to develop such collaboration projects, depending on firms' characteristics.

For engineering-based firms, developing new collaboration projects with PROs on the basis of social and geographical proximity is relatively cheaper and faster than heavily investing in internal R&D to become more cognitively proximate to such PROs. However, this strategy is less flexible because the potential collaboration partners are limited to the PROs with which a firm already has social relations and geographical proximity. Hence, the firm may use social and geographical proximity as a first step in developing collaborations with PROs and may later partner with other PROs when the firm has increased its cognitive proximity to them.

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