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How do dimensions of proximity relate to the outcomes of collaboration? A survey of knowledge-intensive networks in the Dutch water sector

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There is a growing body of literature on the importance of proximity for innovation and other knowledge-related outcomes. We examine the impact of geographical, social, organisational, and cognitive proximity for a heterogeneous population, including people from academia, knowledge institutes, industry, and government. We analyse data on 1020 ego–alter relationships, derived from a survey among water professionals in the Netherlands. The use of survey data allows for more refined indicators of proximity and more diverse collaboration outcomes than those common in the literature. Social and cognitive proximity have a positive effect for all outcomes examined. Geographical and organisational proximity have a negative effect on hard (tangible) outcomes yet a weak positive (if any) effect on soft (intangible) outcomes. We do not find evidence for the suggestions in the conceptual literature that proximity follows an inverted U-curve where most outcomes are achieved in relations with some but not too much proximity.

Keywords: knowledge transfer; proximity dimensions; collaboration; innovation; the Netherlands

JEL Classification: D85; O31; O33

1. Introduction

The literature agrees on the benefits of collaboration in knowledge-intensive processes (Hagedoorn, Link, and Vonortas 2000; Hoekman, Frenken, and Tijssen 2010; Katz and Martin 1997). Much less is known about configurations that stimulate effective collaboration, leading to targeted outcomes such as knowledge production, innovation and joint publications. Research policy favours specific collaborations, such as public–private partnerships, while it is not clear what conditions are favourable for what kind of outcomes. Various studies suggest that proximity is a key concept in understanding the configurations of collaboration in knowledge production

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(see Boschma 2005 for an overview). The basic premise is that proximate people have a tendency to collaborate, as it is easier to communicate with people who are close. On the other hand, the advantage of collaboration may disappear when people become 'too close' (Nooteboom et al. 2007). There is a substantial body of work on the relationship between geography and innovation (Autant-Bernard et al. 2007; Broekel and Boschma 2012; Porter 2000). Gravity models show that geographic proximity can explain co-authorship in scientific publications (Hoekman, Frenken, and Tijssen 2010; Ponds, Oort, and Frenken 2007). Ethnographic studies, for example, on business development and technology acquisition around Conseil Européen pour la Recherche Nucléaire, show the importance of cognitive and social proximity for successful collaboration (Autio, Hameri, and Vuola 2004).

The growing body of the literature on proximity is rich and diverse, but contributions often share three limitations. First, most empirical studies focus on one dimension of proximity. The earlier work by economic geographers on co-location has led to the insight that in addition to geographical proximity other dimensions are relevant in knowledge production and innovation (Boschma 2005). This has resulted in studies that analyse the effect of diverse dimensions of proximity in recent years (Aguiléra, Lethiais, and Rallet 2012; Broekel and Boschma 2012). Second, the analysis of the impact of proximity on the outcomes of collaboration mostly focuses on publications and patents. The focus on publications and patents as proxies for learning, knowledge production or innovation may give an incomplete picture of the effect of proximity. The use of data sets on patents and publications without additional data limits the possible indicators of proximity to the variables stored in the data set, which sometimes are at best proxies for the dimensions of proximity. Third, they consider a relatively homogeneous group of people from one societal sector (for example, scientists or professionals from the industry). Analysing a homogeneous group of actors (all from science, or all firms, for example) may give a limited view on the effect of proximity. Proximity may work differently in a field with relatively much organisational and cognitive variance (i.e. people with strongly different expertises and from very different organisations) compared with a field that is relatively homogeneous.

In this paper, we contribute to the proximity literature by investigating the relation between different outcomes of collaboration (such as publications, innovations, but also more intangible outcomes like exchange of ideas) and the degree of geographical, social, cognitive, and organisational proximity between collaborators. In our data, we do not distinguish between outcomes of collaboration that are expected and that are already achieved. Therefore, throughout this article, when we refer to outcomes, this concerns both expected and achieved outcomes. We elaborate further on this point in Section 3.5. Our empirical analysis is based on a survey among professionals in the Dutch water sector. The water sector involves a wide variety of knowledge disciplines and societal sectors, resulting in a large variety in organisational and cognitive backgrounds of collaborators. The use of a survey allows us to use a larger number of indicators for different dimensions of proximity than the analysis of patents and publications. Our paper is part of a recent trend to use surveys to assess the different dimensions of proximity. Aguiléra, Lethiais, and Rallet (2012) have used survey data in their study on the impact of proximity on network formation to develop a typology of eight different types of relationships, each with their own geographical scale and need for coordination. Ferru (2010) combines contract data with survey data. This allows her to show that the pattern of local partnerships tends to be reinforced over time, because people prefer to collaborate with alters they know – even if those are not the most appropriate partners in terms of available resources – over searching for new partners. Weterings and Ponds (2009) use a survey and (for geographical proximity)

arrive at different conclusions than conventional studies: they show that although most collaborations occur within a region, the most valuable knowledge exchange takes place in inter-regional collaborations.

The remainder of this paper is structured as follows. In Section 2, we introduce a conceptual framework and explain how it relates to earlier research. In Section 3, we explain how we applied the concepts to our case and how we have collected our data. In Section 4, we discuss the results. In Section 5, we reflect on these findings and provide further analysis. In Section 6, we draw conclusions and raise some issues for future research.

2. Conceptual framework

We apply a multidimensional model of proximity that includes a geographical, social, organisational and a cognitive dimension between two collaborators, the ego and the alter. Our aim is to find out what dimensions of proximity are conducive to the outcomes of collaboration.

2.1. Dimensions of proximity

The first literature on proximity focused entirely on geographical proximity (Audretsch and Feldman 1996). Over time other dimensions, such as organisational, institutional, cultural, cognitive, technological, and social proximity have been added. Authors have come up with a wide range of categories of proximity, each with their own definition and operationalisation (see for an overview Knoben and Oerlemans 2006). The common denominator of these dimensions is that being proximate in any of them can enhance coordination, reduce uncertainty and thus contribute to knowledge production and innovation (Boschma 2005). Review papers by Boschma (2005) and Knoben and Oerlemans (2006) show that there is much overlap between some of the concepts in the literature, either because different labels are used for the same idea or because umbrella terms are used that include several other concepts. To give one example: what is termed as 'social proximity' in this paper, is also called 'personal proximity' or 'relational proximity' by others (Coenen, Moodysson, and Asheim 2004; Schamp, Rentmeister, and Lo 2004). Knoben and Oerlemans (2006) distinguish three dimensions: organisational, cognitive (or technological), and geographical proximity. Boschma (2005) identifies two more: social and institutional.

In our analysis, we distinguish four dimensions of proximity, namely social, organisational, cognitive, and geographical. We disregard the institutional dimension. Institutional proximity entails humanly devised constraints that structure political, social, and economic interaction (North 1991). At the dyadic level of individual interactions, institutional differences and similarities can be considered as part of organisational proximity (Knoben and Oerlemans 2006). Ponds, Oort and Frenken (2007), for example, use the difference between academic and non-academic organisations as an indicator of institutional proximity. In our framework, this is part of organisational proximity. At the level of communities and systems, institutional proximity can also concern differences in values and norms, the macrolevel in North's framework. This is sometimes measured using proxies such as language or shared law systems (Boschma 2005). In a small and culturally homogeneous country, measuring such differences with data on one sector would require questions that are difficult to implement concisely in a survey (Aguiléra, Lethiais, and Rallet 2012). We do distinguish between organisational and social proximity. Social proximity refers to personal aspects of collaboration (mutual trust and kinship), whereas organisational proximity (at the dyadic level) focuses on similarities and differences in the organisational context. The same four

Table 1. Overview of the analysed dimensions of proximity.

Proximity dimension	Description	References
Geographical	Distance 'as the crow flies' between working place of ego and alter (sometimes combined with other geographical indicators such as national and regional borders)	Aguiléra, Lethiais and Rallet (2012), Aldieri (2011), Autant-Bernard et al. (2007), Balland (2012), Broekel and Boschma (2012), Cunningham and Werker (2012), Ferru (2010), and Hoekman, Frenken, and Tijssen (2010)
Social	Social embeddedness of ego and alter (involving trust, based on friendship, kinship, and personal experiences)	Aguiléra, Lethiais and Rallet (2012), Autant-Bernard et al. (2007), Balland (2012), Broekel and Boschma (2012), Cunningham and Werker (2012), Fleming, King, and Juda (2007), and Ter Wal (2009)
Organisational	Similarity in incentives and routines between organisations of ego and alter	Aguiléra, Lethiais, and Rallet (2012), Balland (2012), Broekel and Boschma (2012), Cunningham and Werker (2012), and Ponds, Oort, and Frenken (2007)
Cognitive	Similarity in the professional knowledge base of ego and alter	Aguiléra, Lethiais, and Rallet (2012), Aldieri (2011), Balland (2012), Broekel and Boschma (2012), Cantner and Meder (2007), Cunningham and Werker (2012), and Nooteboom et al. (2007)

dimensions of proximity are selected in a recent empirical study on the Dutch aviation industry (Broekel and Boschma 2012). In Table 1, we give an overview of the dimensions of proximity we use, with references to recent empirical works that use the same (or a similar) concept. In Section 3.2, we describe in more detail how these four dimensions are operationalised and measured in our study.

2.2. Outcomes of collaboration

Aguiléra, Lethiais, and Rallet (2012) distinguish three streams of the literature on proximity. The first stream studies the links between proximity and network formation (Autant-Bernard et al. 2007; Ferru 2010). The second stream analyses the impact of proximity on the economic performance of firms (Broekel and Boschma 2012). The third stream investigates the impact of the different dimensions of proximity on knowledge production and sharing (Boschma 2005; Knoben and Oerlemans 2006). Our study can be positioned in this last stream. An overview of findings in the literature since 2005 is provided in Table 2. It immediately stands out from this overview that earlier studies either measure the impact on innovative performance, or on one single type of outcome.

Table 2 also makes clear that, so far, the literature focused on hard, tangible outcomes of collaboration. Many studies are based on data about co-authorship of publications (Hoekman, Frenken, and Tijssen 2010) or co-ownership of patents (e.g. Wal 2009; for a

Table 2. Overview literature findings since 2005 on the effect of the dimensions of proximity.

Source	Outcome	Scale/ field	Geo	Soc	Org	Cogn	Findings
Aldieri (2011)	Patents	Europe, the USA, and Japan	+			+	Knowledge streams from patent citations stronger between proximate firms, both geographically and technologically. Geographical effect stronger in Europe
Autant-Bernard et al. (2007)	Projects in Framework Programme6	EU; nanotech	0/+	+			Social distance matters more than geographical distance. Geographical does not matter for firms involved in more projects
Balland (2012)	Projects in FP6	EU; satellite navigation	+	0	+	0	Cognitive proximity does not have an effect because organisations also need access to different knowledge in the industry branch
Bouba-Olga, Ferru and Pépin (2012)	Science–industry alliances	France	+		+		Strong differences between regions in the effects of geographical and sectoral proximity
Broekel and Boschma (2012)	Innovative performance (interviews)	The Dutch aviation industry	+	+	0	−	Strong evidence that too much cognitive proximity lowered firms' innovative performance, and organisational proximity did not have an effect
Cantner and Meder (2007)	Patents	Germany				+	Technological overlap of two organisations increases probability that they cooperate
Cunningham and Werker (2012)	Publications	EU; nanotech	+		+	+	Geographical proximity not only physical distance, but also territorial. Cognitive proximity neither too far nor too distant. Organisational proximity only indirectly: non-academic partners are cognitively more proximate
Hoekman, Frenken, and Tijssen (2010)	Publications	EU	+				Impact of physical distance is stable over time; impact of territorial borders has decreased over time (2000–2007)
Nooteboom et al. (2007)	Innovative performance (survey)	Chemical, pharmaceutical, and automotive				+/−	U-shaped relationship between cognitive proximity and innovative performance. The effect is stronger in explorative collaborations than in exploitative collaborations
Ponds, Oort, and Frenken (2007)	Publications	8 Dutch scientific fields	+		+		Geographical proximity has a stronger effect if organisational proximity is lower
Wal (2009)	Patents	Germany biotech	+	+		+/−	Social proximity is the strongest predictor. Controlling for social, the effect of geographical is weak. The effect of cognitive is positive, but turns negative if controlling for the other two dimensions
Weterings and Ponds (2009)	Knowledge exchange (survey)	Dutch computing and life sciences	+				Firms have more knowledge exchange with proximate others, but the knowledge flows exchanged with more distant partners are valued higher

more extensive overview see Bouba-Olga, Ferru, and Pépin 2012). There are large data sets with these types of data, which allows for an analysis of many different relations. However, knowledge production and innovation entail much more than can be captured in publications and patents. Many innovations, for example, are not patented but protected in other ways or even shared openly. Especially, non-profit organisations store and share their knowledge in other forms than patents and scientific publications, for example, by personal communication between people or in non-scientific publications.

It is an important question whether proximity has the same impact on tacit knowledge (which is often shared informally and cannot be traced in patents or journal publications) as on formal codified knowledge (Aguiléra, Lethiais, and Rallet 2012; Balland, Suire, and Vicente 2013). To date, there is little empirical work on the relation between proximity and informal knowledge production and sharing between collaborators. An exception is the study of Aguiléra, Lethiais, and Rallet (2012) who assume that collaborators who indicate a great need of coordination will also exchange tacit knowledge. They then show that non-spatial proximities are especially important in relations in need of coordination. Another exception is the work of Weterings and Ponds (2009) who excluded all formal R&D collaborations in their study on the difference between intra-regional and inter-regional knowledge flows. Attention for informal knowledge production and exchange is especially important in the water sector where patenting is rare even for profit organisations, and where many non-profit organisations are involved in knowledge production.

2.3. The relation between proximity and outcomes of collaboration

Each dimension of proximity has an impact on the outcomes of collaboration. We briefly discuss earlier findings per dimension.

Geographical proximity can stimulate and facilitate processes of learning and innovation, sometimes by complementing or substituting other dimensions of proximity (Rallet and Torre 1999). Earlier studies on patents and publications confirm that collaboration is more intense across smaller geographical distances (see Bouba-Olga, Ferru, and Pépin 2012 for an overview). However, Weterings and Ponds (2009) use data from a telephone survey to show that, although most collaborations are geographically proximate, the ones across larger distances are considered more valuable and more often concern knowledge exchange on technological issues.

Social proximity is considered to facilitate and foster joint knowledge production and knowledge exchange (Broekel and Boschma 2012). It has been shown empirically that social proximity (using the proxy of a collaboration history in the past) leads to more joint patents (Wal 2009). For collaboration in European Union (EU) Framework Programme projects on micro- and nanotechnologies, the number of common acquaintances in the network and network distance have an effect on the likelihood of collaboration (Autant-Bernard et al. 2007). Then again, Balland (2012) shows for Framework Programme projects in the navigation industry that the partners of partners in the project (which he defines as social proximity) are not more likely to interact than random actors. It is also argued that too much social proximity can be detrimental for effective learning and innovation because a relationship largely based on trust and loyalty may lead to an underestimation of opportunistic behaviour (Boschma 2005). However, to the best of our knowledge, this has yet to be proven empirically.

Organisational proximity is said to reduce the uncertainty and opportunism involved in knowledge creation. It provides control mechanisms required to protect intellectual property and ensure rewards for the knowledge produced (Boschma 2005). Broekel and Boschma

(2012) show a positive effect of organisational proximity on knowledge network formation among firms, but no effect on their innovative performance. Cunningham and Werker (2012) find that collaborations with only academic partners are better able to overcome large technical distances than mixed or non-academic collaborations. There is no empirical evidence for a negative effect of too much organisational proximity on (forms of) knowledge production and exchange.

Regarding cognitive proximity, Nooteboom (1999) argued that for novelty cognitive distance is required, small enough to be able to understand each other and efficiently process the acquired information, yet large enough to yield new knowledge. The empirical evidence is mixed. Cantner and Meder (2007) use patent data to show that technological overlap between collaborators contributes to the likelihood that they collaborate. Wal (2009), also using patent data, finds a weak negative effect of cognitive proximity in a multivariate model that controls for geographical and social proximity, but a positive effect in a univariate model. Broekel and Boschma (2012) find a negative effect on innovative performance. Cantner and Meder (2007) explicitly test for an inverted U-curve, but do not find one. However, Nooteboom et al. (2007) find an inverted U-curve for explorative patents (though not for exploitative patents).

Few studies include an interaction effect between different dimensions of proximity. They examine the effect on network formation and give mixed results. Breschi and Lissoni (2003) find with patent data that geographical proximity is only relevant if there is a social connection between patents. Ponds, Oort, and Frenken (2007) find a smaller effect for geographical proximity in collaborations between academic organisations than in collaborations between academic and non-academic organisations. However, Broekel and Boschma (2012) find that geographical, social, organisational, and cognitive proximity all four have an effect on knowledge network formation, also when controlling for the other dimensions. This is to the best of our knowledge the only study that includes interaction effects and tests four dimensions. Cunningham and Werker (2012) test a model with geographical, organisational, and technical proximity. They find that geographical proximity is statistically most significant, although technical proximity has the largest effect. Organisational proximity only has an indirect effect; the different types of organisations differ in their absorption of new knowledge, with non-academic organisations being more specialised. Wal (2009) finds that the positive effect of cognitive proximity turns into a weak negative effect if he controls for geographical and social proximity.

Our hypothesis is that proximity has a different effect on different outcomes of collaboration. We expect that proximate relations yield 'everyday' outcomes of knowledge exchange; the intangible outcomes like exchange of knowledge or support for ideas. Because the more distant relations have higher transaction and coordination costs, such relations probably aim for specific, tangible outcomes like innovation or publications.

3. Data and methods

Our results are based on a survey among the members of the Royal Dutch Water Network. The network is a society of 3468 individual water professionals aiming to increase their expertise by exchanging experiences and knowledge. All members have received a personal invitation to answer a variety of questions. Respondents (egos) have been asked to:

- provide information on personal characteristics (age, the educational level, etc.);
- randomly select three persons from their external professional network (alters);
- provide their perspective on a number of personal characteristics of those alters;

- assess the proximity of the relation by answering questions on each dimension; and
- identify the benefits that were expected or had been achieved in each relationship.

A total of 618 respondents have returned the questionnaire. Since each respondent was asked to provide information on three relationships, the maximum number of relationships that can theoretically be analysed is 1854. However, not all respondents have provided complete information on all three relations. In this paper, we only analyse the 1020 relationships for which all questions were answered. There are a number of limitations to the survey data. First, we have only asked the respondents about their perception of the collaboration with three of their alters; we cannot observe how that differs from the perception of the alters on the same collaboration. Second, the survey data are inherently subjective in nature; we measure the perceptions of the respondents. Third, there may be biases by the alters in the selection of alters to report on. We elaborate in more detail on these limitations in Section 5.3.

3.1. The Dutch water sector

Our data have been collected in the water sector in the Netherlands. The Netherlands is a small country in geographical terms; relatively small differences in distance can have a considerable impact on people's perception. However, it is densely populated and shows high internal diversity. About 50% of the country (the western part, where about 70% of its gross domestic product is earned) is low-lying and flood-prone, because, although safely behind dikes, it is below the sea level (Kabat et al. 2005). One can understand that water safety and security are considered important. This diversity in combination with its relatively compact make the country interesting for proximity research.

Proximity mechanisms may have different effects in different sectors. Vinciguerra et al. (2011) show that the importance of geographical proximity may be technology-specific. We study the water sector; this is delineated as all activities related to the water cycle (production, collection, distribution (grid maintenance) and treatment of drinking water and wastewater; water management). The water sector is directly linked to grand societal challenges. Rockström et al. (2009) have identified nine planetary boundaries; transgressing them is potentially catastrophic because of the risk of transgressing thresholds that trigger abrupt environmental changes in continental and even planetary-scale systems. A deeper understanding of water and water management is required for several of these planetary boundaries, notably global freshwater use, climate change and the nitrogen and phosphorus cycle. This is also recognised by policy-makers; it is, for example, directly related to several of the grand challenges mentioned in Horizon 2020 as crucial for Europe (notably climate change and depletion of natural resources and food security and sustainable agriculture).

Regarding organisational and cognitive proximity, it is important to note that the Dutch water sector itself entails a set of heterogeneous actors. A water sector typically envelopes a whole range of intertwined organisations specific, yet complementary roles. Therefore, when we refer to Dutch 'water sector' we first not only mean the collaborative community of public organisations such as water utilities (10 drinking water companies), water boards (25), and municipalities (408). But also the attached industrial conglomerate of service providers, R&D departments of technology manufacturers as well as the public research infrastructure of universities and applied research institutes and research intermediaries who commission research. Moreover, private consultants play an important role in the generation and transfer of knowledge to the operations (Muizer and van den Bergh 2002).

In many aspects, the Dutch water sector is similar to the ones in other European countries. Its utilities are public as is the case in the vast majority of countries in Europe, with the exception of the UK and France. However, the consolidation process in a sector that is, worldwide, notorious for its fragmentation, is remarkable in the Netherlands. The scale and geographical coverage of the drinking water companies has increased substantially over the past 70 years. In 1940, there were 210 water supply companies in the Netherlands; this decreased to 14 in 2004 (Moel, Verberk, and Dijk 2006) and 10 at present. All companies have their own service area; there is hence no direct competition in drinking water supply and distribution or wastewater treatment. The consolidation in the domain of wastewater treatment and water safety (waterboards) is even more considerable. The number decreased from approximately 2600 in 1945 to 25 in 2013. Vierssen (2012) estimates that for Europe as a whole, the Netherlands has meanwhile scaled up operations with a factor 100 as compared with the average situation in Europe.

However, as Thomas and Ford (2005) state, there are concerns that because the sector is too orthodox and lacks an innovative culture, it will fail to deliver the breakthroughs required for high-quality water services in the coming century. This is attributed to a lack of integration and collaboration between actors of different types (e.g. firms with knowledge institutes), and myopia with regard to technology and innovation, which is reinforced by regulatory and policy frameworks (Thomas and Ford 2005).

The Dutch water sector would like to invest in knowledge production and innovation to strengthen its (international) position (Stumpe 2011); this will require stronger collaboration, both between different organisation types and between different subsections of the water sector (Muizer and van den Bergh 2002). Traditionally, the sector is strongly organised in pillars (such as drinking water, wastewater, distribution, and water management); there is recently attention for the need to integrate those. Governmental agencies from across the sector (from national agencies to municipalities and from drinking water-related agencies to water management agencies) have expressed their willingness to collaborate with private parties and research organisations on innovative projects; water also has a clear position in the Dutch sectoral innovation policy (Stumpe 2011). There is also more attention for integration with other sectors; water management, for example, is now more integrated with related policy fields such as nature preservation, spatial planning, agriculture than a few decades ago; parties in the water sector are in have interactions with other relevant actors (Brugge 2009). It is hence a very interesting field to test how mechanisms like organisational and cognitive proximity currently shape patterns of collaboration in knowledge production.

3.2. Operationalising dimensions of proximity

The choice for a survey to collect the data allows for more refined indicators of the other dimensions of proximity than the ones that are common in the literature. Per dimension we will explain how it is usually measured and how our measures relate to the definition of each dimension.

Geographical proximity was measured by asking the respondents to list both the city where they (most often) work and the city where their relations work. Due to a technical error, the cities of the relations were not stored in our data set. However, other details (such as the name of the organisation) were stored, and we have used that information to retrieve the cities of the relations where possible. We have identified the latitude and longitude of each city and calculated the distance between each pair of cities using the formula for

great-circle distances (Sinnott 1984). In other words, distances refer to the shortest possible distance between two points on a sphere, 'as the crow flies'.

Social proximity refers to the social embeddedness of the collaboration. Social embeddedness involves trust, based on friendship, kinship, personal experiences (Boschma 2005; Broekel and Boschma 2012). This cannot be inferred directly from data on patents or publications. Many studies therefore measure the social connectedness based on the collaboration history of actors (such as earlier co-authorships) (Breschi and Lissoni 2003) or the geodesic distance in a social network (Balland 2012; Cunningham and Werker 2012) as a proxy for social proximity. Such social connectedness can indeed be a source and indication of social proximity: the fact that an ego repeatedly collaborates with the same alter indicates a basic form of mutual trust and social proximity. However, the fact that collaborators do not have a formal track record of past publications does not imply they are not socially proximate. Moreover, the fact that people have a history of collaboration may say as much about their cognitive proximity (their ability to understand each other's knowledge so they can fruitfully collaborate) as about their social proximity. We have hence decided to measure social proximity more directly by asking about trust and the nature of the relationship. Trust is considered a central element of social proximity. For measuring trust (the items Trust, Effort, and Share), we have used questions from existing surveys on trust (Levin and Cross 2004; McAllister 1995). In addition, we asked for details about the nature of the relationship, for example, whether ego and alter know each other as peers in former jobs or went to school together or have a contractual relationship. By asking for personal characteristics of both the respondent and his or her relations, we could also examine whether similarity in age and gender contributes to social proximity.

Organisational proximity can be defined as the degree of similarity in routines and incentive mechanisms (Metcalfe 1994). In innovation literature a distinction is often made between profit and non-profit organisations, as they clearly have different incentive mechanisms and, hence, different routines. Profit organisations, for example, have incentives to hide knowledge from their competitors, whereas non-profit organisations often have a mission for open knowledge exchange (Broekel and Boschma 2012). Given the large variety of organisations in our sample, we have extended the possible categories to four societal sectors (business, government, academia, and non-governmental organisation (NGO)). We have added a question to ask specifically about the differences in intellectual property protection between the organisations of alter and ego. Moreover, in the literature on organisational cultures (Ashkanasy, Wilderom, and Peterson 2000; Delobbe, Haccoun, and Vandenberghe 2002; Denison and Mishra 1995; Hofstede 1998) many indicators are described to give some basic characterisation of an organisation, focusing on differences in incentive mechanisms and routines in organisations. They are therefore useful for measuring organisational proximity. As the range of organisations in our group of respondents is very wide, we have chosen a few universal indicators. They measure a focus on procedures versus results, the capacity to adapt to new circumstances, the strictness of planning and financial management and the freedom to engage in external contacts.[1]

Cognitive proximity concerns the similarity in the knowledge base of alter and ego (Aguiléra, Lethiais, and Rallet 2012; Boschma 2005). It is very similar to the concept of technological proximity. However, technological proximity is often defined a bit more narrowly as differences in the technical knowledge base of collaborators (Knoben and Oerlemans 2006). This is usually operationalised as a similarity in technical class, e.g. on the basis of industrial classifications (such as the classification by the Nomenclature statistique des activités économiques dans la Communauté européenne) or by creating technological

profiles for each organisation based on patent classifications (Aguiléra, Lethiais, and Rallet 2012; Wal 2009). Cognitive proximity is somewhat broader; it refers to all knowledge actors hold, and their ability to interpret or absorb the knowledge exchanged (Mattes 2012). We have measured the cognitive distance using items that indicate whether ego and alter share specific expertise. Using the same concepts and terms (speaking the same 'language') is an indicator of a similar knowledge base. We have therefore included a question on the extent to which alter and ego use the same jargon when they interact. The same goes for expertise on specific instruments and machinery, the second indicator we have included. Furthermore, they indicate to which part of the water cycle their own work and that of their relations belongs. This is an additional measure for overlap in technical expertise.

3.3. The explanatory variables

The four dimensions of proximity have been measured using different questions, thus producing the explanatory variables in our model. Table 3 describes the explanatory variables in detail. All ordinal variables in this table were measured as a 5- or 6-point Likert scale.

Geographic proximity is defined as the inverse of geodesic distance between the cities where ego and alter work. The more proximate cities are the shorter the distance between them. By using the inverse, more proximate relations have a higher score, in line with the other variables. Many scholars employ further alterations to avoid the problem that the inverse of zero distance is not defined (see, e.g. Aldieri and Cincera 2009). However, the smallest distance in our case is 3.5 km between cities. For collaboration within the same city we have assumed a fixed distance. Sensitivity analysis shows that different standard values for this fixed distance do not alter the effect size or significance level of any of the results. We have tested several values in a range from 1 to 5 km and we use a distance of 5 km as standard value in the reported figures.

Social proximity (SP) has been operationalised using two groups of variables. SP-Effort, SP-Trust and SP-Share provide a direct indication of social proximity, while variables such as age and gender, which have a primary function as control variable, are also informative with respect to social proximity. SP-Effort, SP-Trust and SP-Share were measured on a 6-point Likert scale. However, in each case, few respondents indicate low proximity. For statistical purposes we have aggregated the scores 1 and 2 into one group.

Age difference, frequency and time are categorical variables. Age difference had five categories (from much younger to much older). As proximity is about distance, the answer categories have been recoded to 'more or less the same age', 'some difference in age', and 'large difference in age'. The question on frequency had six response categories, but the frequencies at both extremes (scores 1 and 6, meeting daily and meeting less than once a year, respectively) were so low that they have been aggregated with their adjacent categories. Time has five categories (from less than 1 year to over 10 years).

The variables that measure organisational proximity were measured on a scale from 'organisation A much more so than organisation B' to 'organisation B much more so than organisation A'. However, from a proximity point of view it does not matter which organisation has a higher score, but rather how large the difference between the two organisations is. Therefore, the answers to these variables have been recoded to a scale ranging from 'there is a large difference between the organisations' to 'the organisations are about the same'.

To identify a common domain in the water sector, respondents were asked to indicate whether or not they considered themselves experts in nine areas within the water sector (collection of drinking water, production of drinking water, distribution of drinking water,

Table 3. Description and descriptive statistics of the explanatory variables.

Variable	Description	N	Median	Min.	Max.	Measurement type
Geographical proximity						
Inverse geodesic distance	The inverse of the geodesic distance between the work locations of ego and alter (measured at city level).	541	.0200 (50.0 km)	.004 (261.4 km)	.29 (3.5 km)	Continous
Social proximity						
SP-Effort:	Willingness of respondent to put effort into something the alter asks him to do.	1010	5	2	6	Ordinal
SP-Trust:	Trust ego has in contributions of alter.	1007	5	2	6	Ordinal
SP-Share:	Willingness of ego to share information with alter.	1013	5	2	6	Ordinal
Same Gender:.	Whether ego and alter are of same gender	1020	1	0	1	Dichotomous
Age difference:	Age difference between ego and alter.	1015	2	1	3	Ordinal
Time:	Time the ego and alter know each other.	1015	4	1	5	Ordinal
Frequency:	Frequency at which ego and alter meet each other.	1020	3	2	5	Ordinal
Private:	Dummy indicating whether or not ego and alter have a non-business relation (one or more of: members of the same association, friend, had the same education, former colleague/employee).	1020	0	0	1	Dichotomous of underlying questions
Organisational proximity						
OP-Adapt:	Degree of difference between organisation of ego and alter in (easily) adapting to new circumstances.	925	2	1	3	Ordinal
OP-Management:	Degree of difference between organisation of ego and alter in strictness of planning and financial management.	900	2	1	3	Ordinal

(*continued*)

Table 3. (*Continued*)

Variable	Description	N	Median	Min.	Max.	Measurement type
OP-External:	Degree of difference between organisation of ego and alter in freedom to initiate relations outside own organisation.	908	3	1	3	Ordinal
OP-Procedures:	Degree of difference between organisation of ego and alter in preferring sticking to procedures over achieving results	881	2	1	3	Ordinal
OP-IP:	Degree of difference between organisation of ego and alter in importance attached to protecting intellectual property.	897	3	1	3	Ordinal
Same Soc. Sector:	whether or not ego and alter work in the same societal sector (business, government, academia, NGO)	1020	0	0	1	Dichotomous
Cognitive proximity						
CP-Jargon:	Degree of difference in technical terms and jargon used by ego and alter.	1019	4	1	5	Ordinal
CP-Machines:	Degree of difference in specialised instruments, software, machines that ego and alter use.	935	3	1	5	Ordinal
Common Domain:	Dummy to indicate whether or not have a specific field in the water sector as a common expertise.	1020	1	0	1	Dichotomous
Common Activity	Dummy to indicate whether or not respondent and alter have a daily activity in common. The daily activities listed included: management, policymaking, research, maintenance, operations.	1020	1	0	1	Dichotomous

Table 4. Results of exploratory factor analysis.

	Components				
Variables	1	2	3	4	5
OP-Adapt:	.746				
OP-Management:	.687				
OP-External:	.647				
OP-Procedures:	.609				
OP-IP:	.594				
Same Soc. Sector:	.440				.401
SP-Effort:		.776			
SP-Trust:		.768			
SP-Share:		.672			
CP-Jargon:			.721		
CP-Machines:			.717		
Common Domain:			.689		
Common Activity			.480		
Time:				.671	
Frequency:		.451		-.565	
Private:				.558	
Age difference:				.444	.405
Same Gender:.					.749

Note: Principal components analysis with an orthogonal rotation (Varimax with Kaiser normalisation), only showing factor loadings over 0.4.

sewerage collection, sewerage transport, wastewater treatment, water management, another water area or no expertise related to the water cycle). The respondents were also asked to indicate whether or not they considered their relations as experts in these fields. Many professionals appear to have expertise in more than one of these areas. Factor analysis revealed five strong clusters: drinking water, sewerage, wastewater treatment, water management and non-water cycle. These five are used to measure if respondents and their relations have at least one common area of expertise.

3.4. Methodology for constructing a variable per dimension

Most dimensions of proximity are operationalised using a set of items that together measure the score on that dimension. We have used exploratory factor analysis to test whether different items measure a common variable. The results are shown in Table 4.

Five factors are distinguished. Factors 1 and 3 contain all items that measure organisational and cognitive proximity, respectively, and no other variables have a substantial loading on them. Factor 2 contains the variables that ask about social aspects of the interactions in the collaboration. We have termed this interaction-based social proximity. Factor 4 contains the variables that were constructed as potential sources of social proximity (age differences, having a private relationship, and the time the collaborators know each other). We have termed this identity-based social proximity, because it is based on comparing aspects of personal identity of ego and alter. Factor 5 captures gender differences, but also loads on age differences and being in the same sector or not. This may be related to the distribution of the data. On average the women in the data set are much younger than the men, which explains the correlation between gender and age differences. Apparently this also relates to having relations in the same sector or not. All in all there are four strong and clear factors: organisational proximity, cognitive proximity, interaction-based social proximity, and identity-based social proximity.

Table 5. Description of the outputs analysed.

Outcome	Description	Times selected (out of 1020)
Innovation	Product, process or organisational innovations. No strict definition in survey; interpretation of respondent whether e.g. incremental innovations are included.	361
Joint publications	Scientific papers as well as policy documents and other publications.	299
Shared knowledge	Any form of knowledge exchange.	654
Patents, copyrights, trademarks	Ideas that are protected with a patent, copyright, trademark.	26
Support for ideas	A bit more specific than knowledge exchange: the relation supports ideas of the respondent.	472
Joint programmes	Collaborations at organisational level (joint programmes, projects, collaboration agreements).	632
More financial turnover	Money inflow for the organisation of the respondent.	209

The scores per item were aggregated to produce a single score per variable, thus allowing us to analyse the outcomes per dimension of proximity. This is done by averaging the scores of the different questions in each factor. Some items were measured on a different scale (e.g. dichotomous rather than a 5-point Likert scale). Diverging items were rescaled in order to combine items with different scales in an aggregate variable. For dichotomous variables (for example, yes or no, male or female) we assigned the two options a value of 1 and 5, respectively, and then included them in the calculation of averages. Sensitivity analysis showed that assigning different values (2 and 4) had no significant influence on the results.

3.5. Outcomes

Six different outcomes will be examined (Table 5). They are measured as variables that can take a value of 0 or 1. They include tangible outcomes of collaboration (such as publications), but also for intangible outcomes (such as exchange of knowledge). To enable comparison with outcomes that are not knowledge-related we also included financial turnover as an outcome. To get some more understanding of how collaborations at the personal level are brought to collaboration at the organisational level, we also included joint programmes as an outcome. Patents, copyrights, and trademarks will be excluded from the analysis, since this item was hardly selected as an outcome. Our survey does not distinguish between achieved and expected outcomes. This implies that some respondents may have indicated results they expect to be realised in the future, while others describe actually achieved results from the past. Of course, the fact that collaborators expect a specific outcome does not imply that this outcome will indeed be realised as expected (see, for example, Ariño and Doz 2000). However, by far most relationships in the data set are well established (almost all alters and egos have known each other for at least a few years). Most outcomes will hence have been realised already, or there is a realistic expectation that they will occur in the (near) future. Moreover, we have no reason to assume that more proximate collaborators have a tendency to report on achieved outcomes while less proximate people would report expected outcomes or vice versa.

4. Results and analysis

Table 6 presents the degree of association between outcomes and the indicators of proximity. We use two statistical approaches that match the skewed distribution of values. For each combination of outcome and proximity variables, we first measure the degree of correlation (Kendall's τ). Then, we compare the group of respondents who do report a specific outcome with the group of respondents who do not report the outcome using a Mann–Whitney test. In this table, we report r for effect size – Mann–Whitney's Z-score divided by the square-root of N – to overcome the Mann–Whitney test's sensitivity to sample size.

4.1. Results per dimension

Geographical proximity has a negative effect on three of the six outcomes: the longer the geographical distance between the two collaborators (ego and alter), the more likely it is that the respondent reports the outcomes innovation, joint publications, or financial turnover. This is in line with Weterings and Ponds (2009), who, also for empirical data on the Netherlands, find that knowledge obtained through non-regional knowledge flows (i.e. flows across larger distances) is valued higher than the knowledge obtained in regional flows. Long-distance collaboration is scarcer than short-distance collaboration, but people are willing to afford higher (transaction) costs and uncertainty if the collaboration will yield valuable outcomes.

Our finding seems to contradict earlier studies on the impact of geographical proximity on publications in other fields than water. Hoekman, Frenken, and Tijssen (2010) find a positive effect: co-authors tend to be geographically proximate (their study is at European rather than national scale, but they also find that a large share of the scientific collaborations takes place within countries). Also studies on patents (a 'hard' outcome too) find a positive effect, such as Wal (2009), who analysed the biotechnology industry in Germany. However, it is important to keep in mind that such studies measure a different thing. Our analysis finds that out of all sorts of collaborations that people have, the (geographically) more distant ones produce joint publications, innovations, and higher turnover. The analyses of patents and publications only observe relations that have actually achieved patents or publications and cannot compare with collaborations in which these outcomes were not realised. Instead, they show that even collaborations with publications and patents occur across smaller distances than we would observe in a world where collaborations are distributed randomly across space. This suggests that geographic proximity has a positive effect on network formation, and a negative effect on specific outcomes.

To confirm this, we have compared the distance between actual collaborators with the distance between any random ego–alter pair in the data set.[2] A Mann–Whitney test proves that collaborators work across much smaller distances than any random combination of egos and alters in the data set ($Z = -16.069$; $p = .000$; median of actual collaborations is 50.0 km; median of potential collaborations is 75.4 km).

There is a clear difference between 'hard' and 'soft' outcomes. Geographical proximity only has an effect on hard (i.e. tangible) outcomes: innovations, joint publications, and financial turnover. It has no effect on soft (i.e. intangible) outcomes: support for ideas, collaboration programmes, and more shared knowledge.

For identity-based social proximity we only find a (positive) effect on support for ideas. Gender correlates with the indicators of identity-based social proximity, but does not belong to the same factor and is hence treated separately. It only has a (positive) effect on innovations and turnover. Interaction-based social proximity has a positive effect on all outcomes.

Table 6. Associations between the outcomes of collaboration and the indicators of proximity.

	Innovation		Joint publications		Financial turnover		Support for ideas		Collaboration programmes		More shared knowledge	
Indicator	Kendall's τ	r	Kendall's τ	r	Kendall's τ	r	Kendall's τ	r	Kendall's τ	r	Kendall's τ	r
Geographical												
Geodesic distance	−.072**	.088	−.076**	.092	−.068**	.082						
Social												
SP-Effort			.145***	.156	.107***	.115	.125***	.145				
SP-Trust	.069**	.074	.092***	.104			.099***	.106			.103***	.110
SP-Share	.063**	.068	.160***	.173	.113***	.122	.163***	.176	.082***	.088	.080***	.087
Frequency	.069**	.072	.100***	.105	.105***	.111	.092***	.097	.089***	.093		
SP_Average	*.071***	*.082*	*.165***	*.191*	*.109***	*.126*	*.176***	*.204*	*.060***	*.069*	*.082***	*.095*
Age difference							−.056*	.058				
Time									−.046	.051		
Private			.084***	.084			.106***	.106			.153***	.153
SP2_Average							*.088***	*.102*				
Same gender	.108***	.108			.073**	.073						
Organisational												
OP-Adapt					−.123***	.128					.060*	.062
OP-Management	−.107***	.111	−.055*	.057	−.110***	.114	−.065**	.068				
OP-External												
OP-Procedures	−.070**	.072	−.058*	.060	−.123***	.128						
OP-IP	−.059*	.062	−.080**	.084								
Same soc. sector	−.088***	.088	−.169***	.169	−.103***	.103			.147***	.147	.058*	.058
OP_Average	*−.088****	*.103*	*−.087****	*.101*	*−.148****	*.172*						
Cognitive												
CP-Jargon							.073**	.078	.069**	.074	.150***	.162
CP-Machines	.089***	.098	.067**	.074			.055*	.061	.066**	.073	.170***	.188
Common Domain	.077**	.077	.136***	.136	.123***	.123	.100***	.100	.100***	.100	.109***	.109
Common activity							.111***	.111				
CP_Average	*.053**	*.063*	*.091****	*.108*	*.049**	*.058*	*.121****	*.142*	*.103****	*.121*	*.153****	*.180*

Note: Only significant variables are reported.

Table 7. Correlations (phi coefficients) between the different outputs of collaboration.

	Innovation	Joint publications	Financial turnover	Shared knowledge	Support for ideas	Joint programmes
Innovation	X	.235***	.056*	.092***	.185***	.035
Joint publications	.235***	X	.068**	.154***	.180***	.150***
Financial turnover	.056*	.068**	X	−.071**	.065**	.013
Shared knowledge	.092***	.154***	−.071**	X	.206***	.167***
Support for ideas	.185***	.180***	.065**	.206***	X	.132***
Joint programmes	.035	.150***	.013	.167***	.132***	X

*$p <= .10$.
**$p <= .05$.
***$p <= .01$.
[where <= stands for less than or equal].

Although the operationalisation of social proximity is different, for hard outcomes this is in line with the findings of Broekel and Boschma (2012) and Wal (2009).

Organisational proximity has a significant negative effect on the hard outcomes: innovations, publications, and financial turnover. The aggregated variable has no effect on the soft outcomes and even among the specific items only a few results were found. We are not aware of any earlier literature that finds an effect for organisational proximity on knowledge-related outcomes. Probably the explanation is similar to geographical proximity: most collaborations are with proximate alters (Broekel and Boschma 2012 find a positive effect on network formation in the Dutch aviation industry), but collaborations across larger organisational distances are selected for the likelihood of producing valuable, hard outcomes. Interestingly, differences in protecting intellectual property are negatively associated with publications and innovations. Apparently, differences in intellectual property regimes do not hinder such outcomes, and may even be necessary for collaboration.

Cognitive proximity has a positive effect on all outcomes. When ego and alter have a common knowledge base, all outcomes are reported more often. As we have seen in the literature overview, the empirical evidence on this point is inconclusive so far. However, our findings corroborate the results of Cantner and Meder (2007) who, based on German patents, find that cognitive similarity is associated with higher odds on outcomes. The strongest effects are found among the soft outcomes. Using the same jargon is only associated with soft outcomes.

We have also tested to what extent the different outcomes are correlated. The results are shown in Table 7. This confirms the existence of hard and soft outcomes; all hard outcomes are correlated at .10 level, all soft outcomes are correlated at .01 level. The weaker correlations among the hard outcomes seem to be because financial turnover is much less knowledge intensive than the other outcomes. The strongest associations are between innovations and joint publications and between shared knowledge and support for ideas.

4.2. The inverted U-shaped curve of proximity

Earlier literature suggests that the relation between proximity and outcomes is not linear but has the shape of an inverted U-curve: it is better to be closer (or more similar) than very far apart (or very different) but being too close or too similar also has a negative effect on outcomes (Boschma 2005). This is assessed by calculating odds ratios.[3]

The odds ratios are shown in Tables 8 and 9. The odds ratios are computed only for the items for which significant results are reported in Table 7. We have not computed ratios for the aggregated variable for each dimension, as it proved to be very complicated to construct an aggregate variable in such a way that the shape of the curves can be analysed.

No odds ratios have been calculated for geographical proximity, as it is a continuous variable. Instead we have computed the values of the median and quartiles of the groups that do or do not report an outcome. This confirms the negative effect of geographical proximity, yet does not suggest an inverted U-shape.

All odds ratios suggest a linear pattern. This is in line with most of the empirical literature that does not report inverted U-curves.[4] There are three possible explanations for the absence of inverted U-curves: (1) respondents report outcomes achieved in a time when they were less proximate to their alters, but they have since become more proximate; (2) the collaborators are all relatively proximate, especially in a geographical (all within the Netherlands) and cognitive (all within the water sector) sense; maybe they are all relatively in such close proximity that we cannot find an inverted U-curve; or (3) the optimal level of proximity is far more proximate than the literature suggests and the downward sloping part of the curve is beyond our measurement scale.

4.3. Interaction effects between the different dimensions

The literature suggests that the different dimensions of proximity may complement or substitute each other (Breschi and Lissoni 2003; Broekel and Boschma 2012). We have applied multivariate logistic regression to quantify the interactions among the dimensions of proximity. The results are shown in Table 10.

The multivariate regression shows that the effect of geographical proximity on the hard outcomes is much smaller (and indeed in two of the three cases insignificant) when controlling for the other three dimensions. This seems to be in line with Ponds, Oort, and Frenken (2007) who find with Dutch publication data that the effect of geographical proximity is smaller if controlling for organisational differences. For the soft outcomes, the effect of social proximity becomes less significant, and in the case of shared knowledge even insignificant. Support for ideas shows a significant effect for organisational proximity, which it did not in the bivariate analysis.

Multivariate analysis hence proves that there are indeed interaction effects among dimensions of proximity, where a lack of proximity in one dimension can be bridged by proximity in other dimensions.

4.4. Soft versus hard outcomes

There is a remarkable difference between what we have termed the 'soft' or intangible outcome (shared knowledge, support for ideas, and collaboration programmes) and the 'hard' or tangible outcomes (innovations, publications, and financial turnover) of a relation. The dimensions of proximity have a different effect on hard outcomes and soft outcomes. Geographical proximity has a negative association with hard outcomes, but no association with soft outcomes. The same goes for organisational proximity. Jargon, an indicator of cognitive proximity, has a positive effect on all soft outcomes and no effect on hard outcomes.

Our expectation was that would be relatively few distant relationships that are only established if the collaborators expect clear pay-offs in the form of hard outcomes, and that proximate relations are more common and involve more informal knowledge sharing with soft outcomes. This clearly holds for geographical and organisational proximity: most

Table 8. Odds ratios for the association between dimensions of proximity and hard outputs.

Items per dimensions of proximity	Innovation					Joint publications					Financial turnover				
	Least proximate			Most proximate		Least proximate			Most proximate		Least proximate			Most proximate	
Social (direct)															
SP-Effort						0.19***	0.41**	1	1.30	1.99***	1.41	0.15***	1	0.93	2.17***
SP-Trust	0.54	0.72	1	1.29	1.39	2.08*	0.28**	1	1.39*	1.65**					
SP-Share	1.08	1.28	1	1.61***	1.55***	0.80	0.48	1	1.54**	2.53***	1.22	0.59	1	1.36	2.25***
Same gender		0.56***	1									0.62**	1		
Social (sources)															
Age difference												0.39*	1	1.43**	1.85**
Time															
Frequency		0.54	1	1.28*	1.17		0.84	1	1.76***	1.29					
Private							0.67***	1							
Organisational															
OP-Adapt												2.85***	1	0.92	
OP-Management		1.01	1	0.61***			0.94	1	0.75*			1.66**	1	0.69**	
OP-External															
OP-Procedures		1.12	1	0.76*			0.84	1	0.72**			2.85***	1	0.92	
OP-IP		1.18	1	0.82			1.86***	1	0.91						
Same soc. sector		1.46***	1				2.23***	1				1.72***	1		
Cognitive															
CP-Jargon															
CP-Machines	0.74	0.75	1	1.27	1.10	0.68	1.10	1	1.19	1.33					
Common Domain		0.69***	1				0.49***	1				0.47***	1		
Common activity															

*$p <= .10$.
**$p <= .05$.
***$p <= .01$.
[where <= stands for less than or equal].

Table 9. Odds ratios for the association between dimensions of proximity and soft outputs.

Items per dimensions of proximity	Support for ideas					Collaboration programmes					More shared knowledge				
	Least proximate			Most proximate		Least proximate			Most proximate		Least proximate			Most proximate	
Social (direct)															
SP-Effort	0.59	0.81	1	1.46**	1.87**										
SP-Trust	0.52	0.59	1	1.32	1.56**						0.32**	0.70	1	1.21	1.65**
SP-Share	0.97	0.64	1	1.86***	2.44***	0.50**	0.50**	1	1.01	1.24	0.58	1.28	1	1.35*	1.52**
Same gender															
Social (sources)															
Age difference		1.20	1	0.82											
Time						1.07	1.17	1	0.99	0.83					
Frequency		0.68	1	1.56***	1.14		0.61	1	1.35**	1.39					
Private		0.63***	1									0.48***	1		
Organisational															
OP-Adapt												0.94	1	1.29*	
OP-Management		0.77	1	0.67***											
OP-External															
OP-Procedures															
OP-IP															
Same soc. sector							0.52***	1				0.77*	1		
Cognitive															
CP-Jargon	0.54	1.01	1	1.32	1.49**	0.23**	0.79	1	0.93	1.37	2.15	0.89	1	1.42**	2.76***
CP-Machines	0.83	0.85	1	1.17	1.01	0.73	0.97	1	1.15	1.21	0.51***	0.72	1	1.44*	1.89*
Common Domain		0.64***	1				0.64***	1				0.61***	1		
Common activity		0.63***	1												

*$p <= .10$.
**$p <= .05$.
***$p <= .01$.
[where <= stands for less than or equal].

Table 10. Multivariate logistic regression of the dimensions of proximity on the outcomes of collaboration.

	Innovation			Joint publications			Financial turnover		
$N = 402$	B	SE	Exp (B) (p)	B	SE	Exp (B) (p)	B	SE	Exp (B) (p)
GP	−3.257	1.970	0.039*	−1.613	1.984	.199	−4.249	2.717	.014
SP_Average	.347	.185	1.415*	.627	1.98	1.872***	.803	.249	2.232***
SP2_Average	.101	.111	1.107	.004	.116	1.004	−.114	.147	.892
OP_Average	−.587	.235	.556**	−.854	.249	.426***	−1.513	.321	.220***
CP_Average	.238	.118	1.268**	.277	.124	1.319**	.087	.151	1.091
Constant	−1.747	1.045	.174*	−2.569	1.105	.077**	−1.643	1.358	.193
Goodness of fit									
−2LL	518.679			484.543			345.651		
X^2	18.29***			27.21***			38.28***		
Cox-Snell R^2	.044			.065			.091		
Nagelkerke R^2	.060			.091			.148		

	Shared knowledge				Support for ideas				Collaboration programmes		
	B	SE	Exp	(B) (p)	B	SE	Exp	(B) (p)			
GP	−.559	1.909		.572	1.873	1.858		6.507	1.551	1.966	4.718
SP_Average	.039	.194		1.039	.686	.187		1.986***	.308	.187	1.361*
SP2_Average	.181	.119		1.199	.100	.109		1.105	−.176	.113	.838
OP_Average	.094	.247		1.099	−.608	.233		.544***	−.145	.237	.865
CP_Average	.431	.121		1.539***	.307	.116		1.360***	.277	.117	1.319**
Constant	−1.620	1.087		.198	−3.161	1.047		.042***	−.859	1.046	.424
Goodness of fit											
−2LL	475.042				527.202				503.527		
X^2	18.44***				29.73***				10.96**		
Cox-Snell R^2	.045				.071				.027		
Nagelkerke R^2	.063				.095				.037		

*p <= .10.
**p <= .05.
***p <= .01.
[where <= stands for less than or equal].

relationships are relatively proximate, but the odds of producing hard outcomes are higher for distant relations than for more proximate relations. This finding matches the result of Arundel and Geuna (2004) who found that European firms that stress the importance of informal contacts to learn about public research results attach lower value to the geographical proximity of the provider of these results. Our result also seems in line with what Ibert (2010) terms relational distance in a case study of one innovation at the intersection of science and business. The (socio) cultural tensions that can come with geographical and organisational distance may be conducive to hard outcomes like innovation. The statistical relationship is different for social proximity. This might be explained by the fact that relations that involve hard, tangible outcomes probably require social proximity and mutual trust to assure the collaborators that collaboration will prove useful and is worth the investment. More common, closer relationships may involve more face-to-face contact and build up social proximity through daily interactions. More or less the same seems to hold for cognitive proximity: both soft and hard outcomes appear to require a relatively high level of cognitive proximity.

A mix of both proximate and distant relationships appears to be optimal for the production and exchange of knowledge-related outcomes in collaboration. This is in line with the work of Uzzi (1997) on overembeddedness, who (for social proximity) also recommends a mix of relationships. The results in this way corroborate the suggestion of a proximity paradox, where being proximate is considered conducive to network formation, yet has a negative impact on innovative performance (Broekel and Boschma 2012).

In addition to that, Cantwell and Santangelo (2002) suggest that actors who are very proximate in one dimension should avoid being proximate in others. They find that cognitively very proximate firms are very reluctant to co-locate. In the literature on related variety it has also been suggested that the negative impact of very high proximity in one dimension could be counterbalanced by a lower proximity in other dimensions (Boschma and Frenken 2010).

4.5. Most relations are proximate

Our data set appears to contain more proximate relationships than distant relationships. This may be partly explained by self-selection. Although we asked respondents explicitly to randomly select three of their professional relationships, it is not unlikely that many respondents focused on socially proximate relationships. This may be deliberate (for example, because of privacy issues) or accidental (because socially proximate collaborators simply came to mind earlier when filling in the survey).

An alternative possibility is that respondents only report about proximate relations because their entire network consists of relatively proximate people. This would suggest that the entire Dutch water sector consists of cliques of people who are proximate in all four dimensions. Potential other collaborators (even within the Dutch water sector) may remain out of sight. Such a situation can be very risky in the longer term. Drejer and Vinding (2007), for example, show that firms with a limited absorptive capacity in sparsely populated regions also tend to collaborate with domestic partners rather than looking abroad. Such behaviour may lead to group-think and can hamper the creation of new knowledge, because the existing knowledge of all people in a clique is already very similar.

5. Conclusions and discussion

5.1. Conclusions

Our analysis clearly shows that proximity matters for the outcomes that people report from collaborations with other professionals in their sector. We have also found that the effects of proximity vary by dimension of proximity and by outcomes. There is a difference between 'hard' outcomes (innovations, publications, and financial turnover) and 'soft' outcomes (shared knowledge, collaboration programmes, and support for ideas). Both geographical proximity and organisational proximity have a negative association with the hard outcomes, and no association with the soft outcomes. Social and cognitive proximity have a positive effect on all six outcomes.

We have also shown that there are interaction effects between the different dimensions of proximity. In particular, the effect of geographical proximity becomes much weaker when controlling for the other dimensions for the hard outcomes. Also, the effect of social proximity becomes weaker for the soft outcomes.

Our empirical analysis does not reveal the inverted U-curves suggested by the literature. The patterns are generally linear, either in a positive or negative direction.

It is important to note that we do not assess the effectiveness of collaboration. Some people in the data set may have only one outcome of collaboration (say joint publications), and yet consider their collaboration highly effective, because they only look for this specific outcome. The results should hence not be interpreted in terms of effective collaboration. Our model reflects how proximity relates to different outcomes of collaboration.

5.2. Discussion

Our empirical case is the Dutch water sector. The effect of proximity may be specific to a country and to the specific configuration and infrastructure of a sector. Caution is needed if our findings are generalised to more generic situations. Proximity may, for example, work differently in geographically larger areas or in regions with more institutional diversity.

As we have explained in Section 3.1, one of the peculiarities of the Dutch water sector is that the service providers (drinking water suppliers and wastewater treatment plants) all have their own geographically discrete service areas and hence do not face any direct competition pressure. This may affect the role of the proximity dimensions for the employees of these organisations. It will probably be easier to build up social proximity with people from other service providers as the levels of trust will be higher than if they were actual competitors. On the other hand, geographical proximity will always be lower between, for example, two water suppliers, as there is per definition just one supplier in each region. However, we do not expect that this phenomenon had a large effect on our findings. The sector consists of many organisations, in a wide range of environments, from regional authorities (non-competitive) to consultants (highly competitive). Moreover, as the results on organisational proximity show, many collaborations exist across different organisation types. The high share of people from environments with a low level of competition (authorities, NGOs, etc.) may contribute to the high scores on social proximity.

In addition, the existence of a dense network with many heterogeneous players in a relatively small country may lead to economies of scale and network externalities: the more players there are in a network, the more valuable it is for entrants to become well embedded in the network. In addition to this, the sector is strongly organised with, for example, network organisations and structures like the regional division of water suppliers. Although this may

influence the fact that many collaborators are proximate to each other, it is not very likely that it also influences the relation between proximity and the outcomes of collaboration.

More empirical work is needed to compare different sectors and different countries or regions. An interesting question is whether or not the different dimensions of proximity can complement or substitute each other. Of course, collaboration is driven by a far more complicated interplay of factors than we have tested in this article. For example, personal characteristics also determine the outcomes of collaboration. Further research should examine how the entire complex of factors (including the various dimensions of proximity) create patterns of collaboration.

5.3. Methodology

The use of survey data has clear benefits: it allows for more refined indicators of proximity and for the analysis of a broader range of outcomes. However, it also introduces potential measurement problems. First, all questions on the relation between alter and ego have only been answered by the egos (the respondents). It is hence their perception of the relation that we measure. Some indicators of proximity (such as the city of work of ego and alter) are not very susceptible to differences in perception, but others, such as the indicators for social and cognitive proximity may be perceived differently by alter and ego. Because we do not use a closed network (egos are free to select alters outside the network of invited respondents), and because it was not required to fill in the names of the alters, we cannot check if there are 'mirroring' responses or how diverging they are. The effect on our findings is probably very small, as we have no reason to assume that the alters systematically have different perceptions on the collaborations than the egos. Moreover, the perceived proximity to a (potential) collaborator will have more impact on the collaboration decisions of an ego than the 'actual', objectified proximity (insofar as that can be measured at all). Second, proximity is dynamic and accumulates over time. This holds especially for social and cognitive proximity. For example, the very fact that an alter and ego publish a report together may increase their cognitive and social proximity. This implies that the direction of the causality between proximity and outcomes is not straightforward. The realisation of the outcomes may have caused collaborators to become more proximate. In fact, this is exactly the assumption of most studies that use patent or publication data sets: earlier co-patents or co-publications are assumed to indicate proximity. Future research should address this dynamic character of proximity. In that respect, it would also be good to not only make an explicit distinction between achieved and expected outcomes in the future, but also to monitor whether expectations regarding outcomes that have not come true in turn also have a reverse impact on the perceived proximity between actors.

5.4. Policy recommendations

Our analysis provides fruitful insights for future policy design. We elaborate on two of them. First, research policy should take the difference between 'hard' and 'soft' outcomes into account. Many research policy instruments steer specifically at some proximity dimensions. EU policy, for example, promotes the emergence of a European Research Area, where knowledge can flow without hindrance of geographical borders, and many national research programmes have specific incentives for collaborations between research organisations and firms. However, as our analysis shows, the dimensions of proximity work differently for different outcomes of collaboration. For fruitful policy design it is hence

useful to first determine what kind of outcomes are to be stimulated exactly, and then per dimension of proximity develop incentives to promote collaborations with high or low proximity.

Second, despite popular belief that geographical proximity will promote fruitful collaboration (which is often the basic premise behind policy to create, for example, science parks), our analysis shows that although indeed many people tend to have geographically proximate collaborations, the more distant collaborations result more often in publications and innovations. That effect becomes smaller if one controls for the other dimensions of proximity. This suggests that initiatives like science parks are probably only effective (in producing more publications and innovations) if they bring together people that would collaborate anyway but would otherwise have to travel long distances to meet.

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Notes

1. To keep the required response time for the survey within limits, we have not asked the respondents to score both their own organisation and that of their collaborators on these items. Instead, we have asked about the difference between the two organisations.
2. The few foreign addresses in the data set were excluded to avoid biases.
3. We use Pearson's chi-square test to determine whether an odds ratio is significantly different from its neutral value and, hence, whether there is an actual effect. For variables that can only take two values, we have corrected with Yates' Continuity Correction. Pearson's chi-square may overestimate the effect, because it (incorrectly) assumes that the discrete probability of observed binomial frequencies in the table can be approximated by the continuous chi-squared distribution. The correction subtracts 0.5 from each difference between observed and expected value, leading to higher *p*-values.
4. An exception is the work by Nooteboom et al. (2007), who show an inverted U-curve for cognitive proximity in explorative patents.

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