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The Role of Personal Proximity in Collaborations: The Case of Dutch Nanotechnology

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Abstract

Proximity in various forms drives collaborations and innovation. The relationship between proximity and innovation has been studied extensively. Most of the studies have focused on dimensions of proximity exogenous to the individual, such as one?s personal characteristics or working style. However, as we will show in this paper, personal proximity ? close similarity in terms of personal traits, behavioural patterns, and the degree to which individuals enjoy each other?s company ? affects research collaborations. In particular, whether and to what extent partners ?click? can make or break a collaboration. We conduct a multiple-case study of research collaborations of Dutch nanotechnology scientists. Our qualitative analysis reveals the role of personal proximity, relative to other dimensions of proximity, in the formation of research collaborations and in shaping their output.

Jelcodes:O32,O33

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Abstract

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Keywords

Personal proximity, collaboration, nanotechnology, universities of technology, The Netherlands

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1. INTRODUCTION

While collaborations between academics and others have been centre-stage for innovation and technological change ever since the Industrial Revolution (Mowery, 2009) they may fail because of a lack of proximity between partners. Different kinds of proximity, i.e., geographical, organizational, institutional, cognitive and social proximity drive innovation (Boschma, 2005) as well as collaborations (e.g. Broekel and Boschma, 2012; Boschma, 2005; Cunningham and Werker, 2012). In particular, the formation and the output of collaborations benefit from partners being sufficiently close in terms of different kinds of proximity. However, to date, discussing the role of proximity is still restricted to dimensions that are almost purely exogenous to the individuals that actually engage in collaborations. At the same time, there is ample reason to believe that elements at a personal level affect collaborations. The very core of academic engagement activities centres around the individual (Perkmann et al., 2013, p.424): "Both academic engagement and commercialisation tend to be individually driven and pursued on a discretionary basis." In order to account for the personal characteristics of the partners we use the concept of personal proximity (cf. Caniëls et al., forthcoming). Personal proximity accounts for the personal features that may affect innovation and collaborations, because it encompasses the degree of similarities in agents' personal characteristics and behaviour. The less different collaboration partners are on these aspects, the more likely a personal 'click' between them develops. In particular, collaborations thrive on "a mutual feeling of acceptance, appreciation and interest in each other's ideas" (Caniëls et al., forthcoming, p.7).

Personal proximity can make or break the deal of collaborating. It enables collaboration, because collaborators – when personally close – are much more likely to form a collaboration as they are understanding each other. A lack of personal proximity may hamper collaboration: "If there is *always* a problem, they are *always* late, they never do as they promised, their interpretations are *always* wrong, then people start to lose confidence." (Interviewee TUE2)[1]. In some instances partners do not get along. At the end of the day it comes down to collaboration with partners who are sufficiently fitting regarding personal features. Only then collaborations have a chance to prosper: "I cannot collaborate with a person who is

[1] Words in italics stressed by interviewee.

technically very good but on a personal scale … is strange." (Interviewee UT1). Mutual respect seems to be crucial for collaborations, because academics have ample degrees of freedom with whom to collaborate. As interviewee UT1 put it: "I think respect is a very key word. … It's not like companies where you have to collaborate because your boss says so. … you *do* collaborate because you like the collaboration."[3]

In this paper we investigate how proximity and in particular personal proximity helps overcoming challenges hampering collaborations with others. Exploring personal proximity helps understanding behaviour of individuals and its impact on the dynamics of knowledge networks. Personal proximity may not only lead to more successful collaborations in terms of output, but also increase the likelihood of establishing, renewing, intensifying and broadening collaborations. It is particularly important to understand the processes governing the relationships between proximity and collaboration as public funding is often misdirected to indirectly support firms and universities in those areas that do not require it (D'Este et al., 2013). Following Caniëls et al. (forthcoming), we suggest that new insights are likely to be found by investigating the under-researched area of personal proximity between collaboration partners.

This paper is organized as follows. To start we discuss the influence of proximity on collaborations (Section 2). In particular, we elaborate on the newly defined term personal proximity and clarify related concepts with particular focus on delineating institutional from organizational proximity and design a comprehensive operationalisation of both concepts. Then, we introduce the research setting, the data and the methodology (Section 3). We combine two data sources. One, quantitative data, i.e. publication analysis, to show the position of the scholars we interviewed in the worldwide nanotechnology network. Two, we employ qualitative data, i.e. interviews with academic scholars at three universities of technology in the Netherlands, in order to analyse the role of personal and related proximities for collaborations in Section 4. Here, we show the implications our results have for theory. We round up our paper with a short summary of our results, policy implications and research questions for future studies (Section 5).

2. Personal Proximity Driving Collaborations: Theoretical Considerations

In the following analysis we want to show how personal proximity drives collaborations. Collaborations themselves have been identified as key in processes of the creation and transfer of knowledge and innovation (Section 2.1). While the relationship between proximity and collaboration has been investigated in the past (e.g. Knoben and Oerlemans, 2006; Capello, 1999; Cunningham and Werker, 2012; D'Este et al., 2013) so far we know little about how personal proximity affects collaborations (Section 2.2).

2.1 COLLABORATIONS IN NETWORKS: CREATING AND TRANSFERRING KNOWLEDGE AND INNOVATION.

In our increasingly complex and complicated world researchers have been creating and transferring knowledge as well as have been driving innovation and technological change in collaborations. Former analyses have provided evidence of the positive impact of, for example, interaction between university and industry in a regional setting (Fritsch and Slavtchev, 2011). By nature, collaborations between different types of public and private agents are core to the functioning of innovation systems (Tödtling and Trippl, 2005; Autio, 1998; Freeman, 1995). By collaboration different organizations involved in the innovation process internalize new knowledge and combine it with knowledge already residing within the firm (Edquist, 2006). As collaborations within academia and between academia and industry contribute substantially to the creation and transfer of knowledge and innovation they received great attention lately (e.g. Caniëls and Van den Bosch, 2011; D'Este and Patel, 2007; Gilsing et al., 2011; Ramos-Vielba et al., 2010). Research collaborations between academics have become crucial to the conduct of scientific research over the past 40-50 years. Not only due to decreased cost of travel and communication and the many digital alternatives for these, but also because of increased specialization requirements in various (inter)disciplinary fields (no individual encompasses the cognitive abilities to do it all), and – in the European Union specifically – because of greater integration of national science systems (Katz and Martin, 1997). Collaboration increases the effectiveness of research processes and the output of collaborations "is greater than the sum of its parts" (Katz and Martin, 1997, p.15). The collaborations between academics are also increasingly of a 'multifaceted' nature, which implies that scientists collaborate to generate more than just co-publications (Jha and Welch,

2010). Prototyping, patenting, writing of research grants, and conference papers are all facets of research collaboration today. These forms of collaboration may lead to the development of more knowledge that is also of a better quality (Jha and Welch, 2010) and generate learning effects through the transfer of tacit knowledge (Bozeman and Corley, 2004). Outside of the realm of science, academics contribute significantly via so-called 'academic engagement' which captures a variety of inter-organizational collaboration mechanisms, often between individuals, targeted to generate utility in both the academic and non-academic sense (Perkmann et al., 2013). Such academic engagement practices may range from collaborative research, to contract research, but also involve more informal relationships between the two parties. These types of collaborations may, although not necessarily so, lead to commercialization of the output they yield or to publications, patents, etc. It is found that academic engagement practices exercise an effect both on the uptake of new industrial R&D activities as well as on the progress of existing innovation efforts by industrial firms (Cohen et al., 2002). It is evident that collaboration is ever more common practice in generating and diffusing knowledge within academia and between academia and industry. Often times, collaboration practices involve interactions of an interpersonal character (Cohen et al., 2002; Schartinger et al., 2002). Hence, the substantial role of the individual collaborator in enabling effective academic engagement to benefit innovation raises the question what enables individuals to work together effectively.

2.2 Personal and Related Kinds of Proximity Enabling or Hindering Collaborations

Proximity enables or hinders collaborations. Although collaboration appears important to further the development and exploitation of key emerging technologies, such as nanotechnology, considerable obstacles lurk ahead. Even in an age where the internet supports communication over great geographical distance, the argument that geography is dead, does not hold (Morgan, 2004). Many studies have illustrated how geographical closeness facilitates local spillovers of knowledge (Audretsch and Feldman, 1996; Cunningham and Werker, 2012; Broekel and Boschma, 2012) or enables firms to exploit the talents of star scientists in their vicinity (Zucker et al., 1998). Hence, lack of geographical proximity may hinder partners in effectively and efficiently collaborating. Apart from the widely discussed geographical dimension of proximity, other kinds of proximity may affect

innovation and collaboration (e.g. Boschma, 2005; Knoben and Oerlemans, 2006): cognitive proximity, institutional proximity, organizational proximity, and social proximity.

Cognitive proximity is defined as similarity in terms of collaborators' expertise and experience in certain knowledge areas (Boschma, 2005). Having expertise and experience in similar knowledge areas facilitates understanding one another, whereas individuals from different cognitive backgrounds may encounter misunderstandings. Absorptive capacity – organizations' ability to explore, assess, and use external knowledge (Cohen and Levinthal, 1990) – is dependent on the overlap of organizations' knowledge bases in order to function (e.g. Lane et al., 2006; Volberda et al., 2010). A firm needs to be able to understand externally available knowledge before this knowledge can be exploited. Caniëls et al. (forthcoming) suggest that reputational standing of individuals can also affect cognitive proximity, as it relates to one's cognitive ability in a certain knowledge field. In case of academic engagement, where university researchers and their counterparts from industry work together, it is likely that there will be some cognitive distance as one party is focused on fundamental advancement of science, whilst the other is oriented towards the application of science. Nevertheless, such cognitive distance is not necessarily an issue. It might in fact increase the potential for innovation as long as knowledge is complementary (Bercovitz and Feldman, 2011; Boschma, 2005). Further, some cognitive distance is necessary to prevent cognitive lock-in, which hampers innovation (Visser and Boschma, 2004; Boschma, 2005).

Institutional proximity is expressed in informal constraints and formal rules and regulations that individuals adhere to in their social interactions (North, 1991; Boschma, 2005). Informal constraints can be common sets of norms and values that individuals and groups identify with (North, 1991), whereas formal rules include actual laws, rules, and regulations (Boschma, 2005). Institutions may also be related to cultural elements (Boschma, 2005). Institutions are humanly devised constraints that develop through histories of social interaction (North, 1991). They may develop both at the macro-level (nations, regions, and cities) and the micro-level (organizations or even dyadic relationships), making it difficult to distinguish institutional proximity from organizational proximity (Knoben and Oerlemans, 2006). In line with Caniëls et al. (forthcoming), we focus on purely those rules and regulations imposed by administrative geographical entities, the macro-level. In this respect, issues with institutional proximity are to be expected in research collaborations with the

greatest potential for success, as empirical evidence shows how it is often the geographically distant collaborations that bring forth higher quality inventions (Bercovitz and Feldman, 2011). Note that such collaborators from distant administrative geographical areas are more likely to be subject to different institutions, such as national legislation regarding intellectual property protection and conditions set for research funding programmes.

Our choice to focus on the macro-level concerning institutional proximity aims to eliminate conceptual and measurement ambiguity that is persistent in proximity literature (acknowledged in Knoben and Oerlemans, 2006). Micro-level institutions, such as firms' appropriability regimes, are captured in our conception of organizational proximity. Furthermore, proximity through social embeddedness in networks, i.e. social proximity, may also lead to the development of institutions at the meso-level. Table 1 shows our reification of the proximity concept based on the distinctive attributes and levels of analysis for each dimension to illustrate our attempt at an overlap-free conceptualization.

Organizational proximity is defined as similarity in terms of organizational goals and organizational institutions (Caniëls et al., forthcoming). Collaborators are organizationally close when they are working towards similar or complementary objectives. Such similarity can express in output goals (e.g. publications, prototypes, patents, obtaining research grants), but also in the time span available to achieve those goals. Further, organizations of different types (e.g. firms, universities, and government) likely impose different institutions at the organizational level. Collaboration partners working in academia are organizationally close as universities are similar in terms of their organizational set-up. This serves to enable collective action by reducing both uncertainty and transaction costs (Boschma, 2005). Conversely, when it comes to academic engagement with firms, there is likely to be a significant difference in the organizational set-up and prospective goals. Firms have an interest in appropriating research findings in order to reap the commercial benefits (Perkmann et al., 2013), while university scientists adhere to the public good principle of their output (David, 2004). Clearly, the organizational set-ups of the academic and industry sector conflict: one requires intellectual property protection whereas the other encourages open communication. Turning from pure discovery-driven to commercialization-driven research activities requires sufficient organizational proximity – similarity in terms of organizational arrangements and organizational goals (Caniëls et al., forthcoming). This is sometimes difficult to achieve in

university-industry collaborations, because academics engage with firms to pursue organizational goals that are different from those of firms (Perkmann et al., 2013), both in time span (long term vs. short term) and in terms of output (broadly, advancement of science vs. product development).

Social proximity involves closeness between individuals in terms of shared informal rules and habits that are the result of a joint socialization process (Caniëls et al., forthcoming), such as those which develop through kinship (Boschma, 2005). The foundations for the concept of social proximity stem from Granovetter's (1985) account of social embeddedness, a mechanism to build trust among individuals and reduce opportunism in social transactions. Importantly, these rules do not stem from groups marked by geographical boundaries, but rather they develop within entities with more blurry boundaries, such as professional organizations, knowledge fields, and social communities (Caniëls et al., forthcoming). In research collaborations between academics, social proximity is likely to exist as scientists affiliate with similar social and professional associations within their field of knowledge. It is less likely for social proximity to exist between potential collaborators from academia and industry. For example, Nilsson et al. (2010) find that conferences (often linked to social communities and professional associations) do attract industry attention but are far from a direct mechanism for transfer.

The concept of personal proximity stems from theoretical contributions to organizational psychology (Caniëls et al., forthcoming). In particular, its principle of 'homophily', which poses that "similarity breeds connection" according to McPherson et al. (2001, p.415). Homophily is found to affect a variety of socio-spatial relationships, such as the development of networks for discussion (Marsden, 1987) and the formation of friendship ties (Verbrugge, 1983). Implications of similarity on the personal level were also identified in ethical decision-making situations, where 'psychological proximity' – involving empathy and identification with another individual on the personal level – was found to impact the moral intensity experienced when face with ethical dilemmas (Jones, 1991; Burger, 1981).

The concept of personal proximity was explicitly mentioned in innovation literature first by Schamp et al. (2004, p.619), who found "personal acquaintances" to constitute an important channel for automotive suppliers to obtain timely information on planning of new models and to secure orders for those. Yet, the concept has not received much further

elaboration since. Caniëls et al. (forthcoming, p.8) conceptualize personal proximity as "differences between individuals regarding specific personality traits, the resulting behavioural patterns, and the degree to which they enjoy the company of each other." The latter, enjoying each other's company, is a result of similarity in terms of traits and behaviour. The more similar the individuals are on the personal level, the more likely a 'click' is to develop. Similarity on the personal level could express itself through one's characteristics (e.g. age, sex, and tenure; Caniëls et al., forthcoming; Zenger and Lawrence, 1989) and traits (e.g. extraversion, openness, and agreeableness; Caniëls et al., Forthcoming; Watson et al., 2000), and the behaviour associated with these characteristics and traits. It is shown that, over the longer term, individuals who click on the personal level work together on more diverse projects (Jha and Welch, 2010). Possibly this is explained by the increased familiarity with each other's behaviour and attitude, which therefore becomes more predictable, as well as the development of personal trust and goodwill over time. Hence, personal proximity may increase the likelihood and success of research collaborations. However, revisiting evidence from organizational psychology also shows how strong personal proximity may lead to misplaced trust or immoral action, where accident observers attribute less responsibility to perpetrators who are personally close, despite of the severity of accidents (Burger, 1981). In research collaborations extensive personal proximity might also make one vulnerable to opportunistic behaviour of the other party or blind to cognitive or organizational mismatches that surface over time. Therefore, we expect that there is a range of personal proximity (close but not too close) that instils sufficient understanding and trust in the partners enabling them to critically assess the collaboration and its progress while working together. This means that we expect an inverse U-shaped relationship between personal proximity and research collaborations' success (Caniëls et al., forthcoming).

Table 1 - Reification of the proximity concept

Proximities	**Distinct attributes**	**Level of analysis**
Geographical	Location (pure physical distance)	Macro
Institutional	Formal and informal rules & regulations imposed by specific administrative geographical territories (including cultural aspects)	Macro (nation / region)
Social	Embeddedness in knowledge fields, professional associations or social communities	Meso (networks)
Organizational	Organizational objectives and organization-specific formal and informal rules & regulations (including aspects of organizational culture)	Meso (organizations)
Cognitive	Knowledge areas of expertise and experience as well as reputational standing	Micro (individual)
Personal	Personal character traits, behavioural patterns, and enjoyment of one another's company	Micro (individual)

Source: adapted, revised and extended based on Caniëls et al. (forthcoming, p.13) and Boschma (2005, p.71)

Empirical work to date has extensively studied the effects of various proximities on collaborations (e.g. Knoben and Oerlemans, 2006; Capello, 1999; Cunningham and Werker, 2012; D'Este et al., 2013). However, it has not uncovered the role of personal proximity focusing on the individual rather than on the collective levels of different kinds. We suggest that, even in cases of sufficient proximity at the collective level, i.e. cognitive, organizational, institutional, or social, personal proximity makes or breaks collaborations between individuals (Caniëls et al., forthcoming). The reason for this is that research collaborations such as academic engagement activities strongly depend on individual decisions and activities (Perkmann et al., 2013).

Existing empirical evidence suggests that collaborations benefit from kinds of proximity mediated by other kinds. To give an example, in European nanotechnology networks "organizational types differ in their uptake of new knowledge. While academic organizations can successfully broker relationships across a wider range of potential topics, non-academic organizations are more productive, but also more specialized in their technological and

collaborative interactions" (Cunningham and Werker, 2012, p.737). In the UK university-industry collaborations of technologically complementary firms in dense clusters have sufficient capabilities to overcome the negative effects of geographical distance (D'Este et al., 2013). Such capabilities are described to be related to inter-firm linkages between these clustered firms, enabling them to establish long-distance relationships as well. Arguably, personal proximity is important in establishing and maintaining local inter-firm linkages within the cluster that ease the formation of collaborations with partners who are not at arm's length distance.

In the following we will particularly focus on the question how personal proximity affects collaborations, together with related kinds of proximity, in the context of research collaborations in nanotechnology. The 'click' or its absence between potential partners affects the formation and the output of collaborations. We suggest that in particular the agency of individuals and key players in innovation systems is partly driven by personal factors. Our starting point are analyses showing the importance of agency exerted by individuals (Tödtling and Trippl, 2012) as well as the importance of relationships between individuals (Rutten and Boekema, 2012) in the creation and transfer of knowledge and innovation.

Personal factors play a role in the formation of collaborations when choosing one collaboration partner over another, for example, Ponomariov and Boardman (2008) show how informal interactions between scientists and industrial firms increase both the likelihood and intensity of research collaboration. Informal interactions may indicate whether individuals are personally proximate to one another. Eventually, deciding to collaborate with one partner and not with another one because of the personal 'click' or a lack thereof may shape networks as a whole, because these individual choices systematically drive the dynamics of networks. To this date we still know very little about the influence of personal features on the formation of collaborations and research networks as a whole. Researchers work, collaborate and in particular shape the dynamics of innovation systems, i.e. the combination of the relatively stable structural elements and institutions such as laws and the agency of individuals and key players such as firms and universities (Tödtling and Trippl, 2012).

3. NANOTECHNOLOGY RESEARCHERS AT DUTCH UNIVERSITIES OF TECHNOLOGY: DATA AND METHODOLOGY

3.1 RESEARCH SETTING: DUTCH NANOTECHNOLOGY RESEARCHERS COLLABORATING IN WORLDWIDE NETWORKS

Analysing Dutch nanotechnology researchers enables us to investigate the role of personal and related kinds of proximity for collaborations in a successful and stable environment. The Netherlands belong to the most important nanotechnology countries within the EU (CEC, 2009). When comparing Dutch nanotechnology publications (Forfas, 2010) and patent applications (Miyazaki and Islam, 2007) with those of European Union (EU) countries, the Netherlands came fourth with Germany being first, the U.K. and France second and third. When looking at the worldwide publications on nanotechnology it turns out that the Netherlands are an important player (cf. this and the following Cunningham and Werker, 2011). The Netherlands do not belong to the about a dozen nations publishing more than 80% of the nanotechnology papers worldwide though, but follow immediately in the next of tier of countries. The Netherlands are ranked 8th in the list of most productive countries worldwide - accounting for number of publications per million citizens.

The Dutch government together with the three Dutch Universities of Technology and other stakeholders have created a successful and stable environment that even served as a benchmark for others, i.e. Ireland (Forfas, 2010). They have been doing so by implementing a systematic Dutch nanotechnology strategy. The three Dutch universities of technology are Delft University of Technology, Eindhoven University of Technology, and the University of Twente.[2] While Delft is located in the populous Western region between Amsterdam and Rotterdam (Randstad), Eindhoven is located in the south, not far from the Belgian and German border (cf. this and the following Cunningham and Werker, 2011). Not only a university of technology but also the High Tech Campus, centered around the research group of global high tech firm Philips, is located in Eindhoven. The University of Twente is located in the Eastern part of the country, close to

[2] There is an additional Dutch university of technology situated in Wageningen. As Wageningen has a particular specialisation in agriculture it does not play a crucial role in nanotechnology. This is also reflected in the fact that Delft University of Technology, Eindhoven University of Technology and University of Twente have formed the 3TU network (3TU, 2014) that has played a crucial role in the context of nanotechnology.

Germany. The region of Twente has undergone a severe restructuring process as it used to be home to a significant textile industry which was in decline in recent decades.

Collaborations have been core to the development and deployment of nanotechnology as this field has been a particularly fertile ground for academic engagement and subsequent commercialization in recent years. Not merely because it is a field with potential for radical innovation, but also because its very roots span a variety of science and engineering disciplines (Porter and Youtie, 2009, p.1038): "nanotechnology research exhibits a high degree of disciplinary diversity. Nano publication centers on materials science (and chemistry and physics). However, nano also significantly involves many other fields, including biomedical sciences, computer sciences & math, environmental sciences, and engineering, among others." Youtie et al. (2008) provide a similar picture of the varied nature of nanotechnology applications, including nanomedicine, nanogels, and nanocomputing devices. Arguably, the field's advancement is dependent on effective integration of disciplines and sectors. This is illustrated neatly by the significant extent to which publications in nanotechnology already cite across marco-disciplines (Porter and Youtie, 2009). To fully grasp what opportunities nanotechnology offers, and to eventually exploit these, scientists and industry from different disciplines and sectors need to understand, and learn from, each other's perspectives. Collaboration would aid the development of nanotechnology overall (Cunningham & Werker, 2012). Shapira and Wang (2010) conclude that funding for nanotechnology research is unlikely to maintain its growth in the US and Europe, and therefore, argue that stakeholders should step up to uphold development of nanotechnology through international collaborations.

The characteristics of nanotechnology lead to the need for collaboration and might be enabled by proximity of different kinds between partners. One, the multidisciplinary nature of nanotechnology research imposes limits on cognitive proximity. Collaborating scientists and / or industrial partners need to be able to understand one another in order for their collaborations to be effective. Such understanding is most likely when collaborators' knowledge bases overlap (Boschma and Lambooy, 1999). The diverging cognitive repertoires of collaborators from different disciplines and sectors pose a challenge to those who wish to collaborate in nanotechnology research. Hence, the issue of overcoming cognitive distance deserves our attention (Porter and Youtie, 2009, p.1039): "…attention needs to be paid to

facilitating the diffusion and absorption of research across disciplines […] findings emphasize the importance of assisting researchers' ability to source knowledge from disparate areas." Two, given the multidisciplinary nature of nanotechnology as well as nanotechnology's observed shift from discovery to commercialization (Shapira et al., 2011; Huang et al., 2011), which implies significantly more involvement of industry in nanotechnology research, it is likely that social and organizational proximity are often suboptimal. That is, scientists might not share membership of similar associations and organizations, nor do they participate extensively in communities that also harbour industrial firms.

3.2 Data Collection: Nanotechnology Researchers at Three Dutch Universities of Technology

To grasp the role of personal and other proximities in the collaborations of Dutch nanotechnology researchers a multiple-case design was adopted (Yin, 2009). We carried out our analysis in four steps. One, we identified and selected interviewees based on theoretical arguments. Two, we conducted the interviews with a selection of Dutch nanotechnology researchers, discussing their collaborations in detail. Three, we analysed relationships between personal and other kinds of proximity on the one hand side as well as the formation and output of collaborations on the other hand. Four, we performed a bibliometric analysis of the global network of nanotechnology researchers and our interviewees' position in it.

By means of theoretical sampling we selected interview partners from the three Dutch universities of technology (Eisenhardt, 1989). These sources were mainly Dutch university and faculty web pages with information on departments and individual scientists as well as personal web pages of researchers. The purpose of this exercise was to identify theoretically contrasting cases in terms of research orientation, based on Stokes' (1997) two dimensional quadrant model of research orientation. This model characterizes the research orientation of individual scientists based on the degree to which research is motivated by (1) a quest for fundamental understanding and/or (2) considerations of use. Four different research orientations in this model are: pure basic, use-inspired, pure applied, and low overall research orientation. We sample interviewees accordingly, disregarding the "low overall" quadrant as any scientist is inherently oriented towards some type of research. A difference in research

orientation may affect the degree to which researchers collaborate and could also affect their ability and propensity to "use" personal proximity. Three researchers from three different Dutch universities of technology were sampled for each type of research orientation, as is shown in Table 2.

Table 2 – Interviewees

Interviewee code	University	Research orientation
TUD1	Delft University of Technology	Pure basic
TUD2	Delft University of Technology	Use-inspired
TUD3	Delft University of Technology	Pure applied
TUE1	Eindhoven University of Technology	Pure basic
TUE2	Eindhoven University of Technology	Use-inspired
TUE3	Eindhoven University of Technology	Pure applied
UT1	University of Twente	Pure basic
UT2	University of Twente	Use-inspired
UT3	University of Twente	Pure applied

Over the period of December 2012 to March 2013 we conducted the interviews. Nine semi-structured interviews were conducted with the interviewees listed in Table 2. The interview guide was inspired by our theoretical framework as to contribute to the internal validity of our study. A case study database was kept using the MaxQDA 11 software tool in order to contribute to our study's reliability (Gibbert et al., 2008). Many interviewees provided us with handwritten lists of their collaborators during the interviews. We logged and added these notes to the case study database, along with the interview transcripts. We used a deductive coding strategy, i.e. codes related directly to the attributes identified with different types of proximity in Table 1. Consequently, we summarized coded segments per case. Based on that, we conducted an analysis of the relationships between codes. In particular, we looked into the co-occurrence of codes in order to obtain indications for possible patterns in the data.

The fourth stage of this study aimed to better understand the role of our interviewees in the worldwide network of nanotechnology researchers by conducting a bibliometric analysis based on publication data from the Web of Science databases using the updated lexical search query by Arora et al. (2013). The purpose of this analysis was twofold: (1) to check whether interviewees with different research orientations are in different network positions and (2) to substantiate our interpretation of interview data, as interviewees in less central positions might "use" personal proximity differently. The overall nanotechnology network over the 2011-

2013 period consists of approximately 637902 researchers who form 23447 connected communities. The largest connected component in the network is a community of 543560 researchers. The six researchers with use-inspired and pure applied research orientations all appear in the largest connected component. When comparing the centrality and eccentricity of our interviewees to those of the five most central and five least central researchers in the network a number of conclusions can be drawn (Appendixes A, B and C). In general, the six researcher are in quite central network positions. They are well-connected in the community of nanotechnology researchers (based on their degree centrality) and are also important to the existence of the network overall (based on their eigenvector centrality). In some cases, the researchers' eccentricity (the maximum distance from the researcher to all other nodes in the network) is even better than the eccentricity of the core scholars. The use-inspired and applied researchers are central in and important to the network, but not in the absolute top of the nanotechnology field. Notably, the three researchers in our sample with a pure basic research orientation do not appear in the network. The explanation for this may be twofold. First, although the recall of the search query is good, an optimal recall of all relevant nanotechnology papers is unlikely. Second, and in relation to the first, the researchers in our sample with a basic research orientation may either be in too specialist or too peripheral niches of the domain for their research to be identified by the query[3]. One interviewee had only very limited publication output over the 2011-2013 period.

4. The Role of Personal Proximity in Collaborations of Dutch Nanotechnology Researchers: Results

4.1 Personal Proximity Moderating Cognitive and Organizational Proximity

4.1.1 Personal Proximity

[3] We recognize that this may also indicate that case selection for interviewees with a basic research orientation was suboptimal. Although they may have a basic research orientation, their affiliation with nanotechnology research might be limited. Hence, additional interviews will be conducted with interviewees who can be regarded as basic in their orientation and who do qualify as nanotechnology researchers according to the bibliometric analysis.

The different dimensions of proximity are expected to impact the formation of collaborations and the output of collaborations. Hence, during the interviews conducted in this study the different dimensions of proximity surface and are discussed in relation to collaborations. Although the various well-researched dimensions of proximity interact to form collaborations and impact their outputs, it is shown that *personal proximity* is of paramount importance in collaborative activities. While it may not always be a prime motive in collaborative choices, its impact should certainly not be underestimated. After discussing his collaborations in great detail, interviewee TUD3 emphasizes the essence of his collaborations once more. The 'click' that develops when collaborators are personally proximate is regarded as a fundamental building block of thriving collaborations.

> "The key element is working with people whom you know, trust and respect." *(Quote 4.1 - Interviewee TUD3)*

Our empirical data show that personal proximity may moderate the relationship between the two and the formation of research collaborations, despite the existence of sufficient organizational, cognitive and other kinds of proximity between collaborators. Enjoying the company of collaborators on a personal level appears to be conducive to prosperous collaborations, it is often said to further improve collaborations (Quote 4.2). When collaborators do not enjoy each other's company, there is no such positive reinforcement of the collaboration. There is abundant evidence that interviewees take into account the personal character traits of their potential collaborators in the formation of collaborative ties. There are many ways of building trust on a personal level by assessing the personal fit with the potential collaborator, such as in Quote 4.3.

> "*[Collaborator's name]* came here, he was a visiting scientist, for 3-4 months. So we drank beers, had things together, had barbeque at home etcetera. *[Question.]* Yes. I've been at his home. Personally. And that makes the collaboration even better except when it doesn't match." *(Quote 4.2 - Interviewee UT1)*

> "Because of a [*Funding organization's name*] grant through which I visited the Institute of [*Specialization*] in [*City X*] and I saw him as an eager guy who wanted to move ahead. That was one observation. […] I had told this person *[colleague]* when he still worked in [*City Y*] that we

> needed for our project [*specialization*] engineers and I told him that if you really want [*specialization*] engineers, we should go to [*City X*], because in The Netherlands they are no longer trained at a sufficiently high level. And that's how *[collaborator's name]* came to [*City Y*]." *(Quote 4.3 - Interviewee TUD2)*

Quote 4.3 exemplifies that the role of the personal dimension of proximity is one moderating the relationship between organizational proximity and cognitive proximity and collaborator selection and collaboration performance. Interviewee TUD2 needed a specialized engineer to fulfil a project's objectives (organizational proximity) and acknowledged that the right expertise and experience (cognitive proximity) was only to be found amongst researchers trained at a specific institute in another country. It was his identification with certain character traits (eagerness and ambition) that led him to select one collaborator out of many that could have fitted the requirements in terms of organizational and cognitive proximity. The moderating role of personal proximity is further illustrated when interviewees discuss situations in which personal proximity was lacking. It is shown that the opportunities created by close-to-optimal cognitive and/or organizational proximity may outweigh any negative effects of a lack of personal proximity. Although interviewees agree that being personally close is important in collaborations and may assert a positive effect, when expertise is attainable that enables one to realize individual or organizational objectives that are regarded as particularly important, many interviewees seem to be willing to set aside personal issues at least for a while. In Quote 4.4 the moderating role of personal proximity, as a fundament to settle issues in collaborative processes, is captured. Yet, the interviewee carefully illustrates that cognitive proximity and organizational proximity can compensate to some degree for a lack of personal proximity. Organizational proximity in terms of objectives may also limit the individual's control over formation of collaborative ties, as seen in Quote 4.5, and, hence, affect the role personal proximity plays in collaborations.

> "I think the quality of output has to do with the real scientific expertise of the other. I think it is very important to have a high degree of personal understanding, because then you can solve all kinds of problems. But for high quality output you need the expertise and then when it becomes important to collaborate with somebody – yeah, simply said – who you do not like, or don't like so much, but you know what that person does is

> really high quality…then you had better listen to him content wise." *(Quote 4.4 - Interviewee UT3)*

> "Knowing each other personally helps to make the collaboration go smoother and better. There are also some collaborations where we did not know each other that well on beforehand, but you were put together by coincidence, and find out that it works well." *(Quote 4.5 - Interviewee TUE2)*

Personal proximity directly impacts the performance of collaborations in terms of output and continuation. Even though an initial assessment of one's personal proximity to the collaborator might have inspired to initiate the collaboration, over time collaborators familiarize further with each other's behavioural patterns. In case mutually accepted behavioural patterns are violated at some point in time, this is likely to lead collaborators to limit or even terminate the collaboration. Hence, personal proximity is dynamic over time. Personal character traits might sometimes indicate that an individual aspires to finish his share of the collaborative work in a timely fashion, yet, over time collaborators might find out that their interpretation of being in time differs. Interviewee TUE2 used the example of continuously belated deliverables hampering his collaborations. Individual collaborators can be close in terms of personal character traits, but behavioural patterns over time might still deviate significantly. Deviation of mutually accepted behavioural patterns would lead interviewee TUD2 to refrain from further collaborations (Quote 4.6).

> "…you can make clear what he does, how it affects you and why you are not liking that. So it becomes a boundary condition for him and he can adjust himself. […] I had one guy who also understood this very well […] but if that is not the case I simply do not want to have the collaboration." *(Quote 4.6 - Interviewee TUD2)*

Violation of perceived personal closeness may not always lead to immediate termination, but it will affect the decision to continue once initial goals are achieved (Quote 4.7).

> "You take on a responsibility. It says nowhere in the responsibility: "Oh, you don't have to do that because you don't like the people." No, that is not part of the responsibility, the responsibility is to get the job done. You accept the funds. Sometimes you discover after a year that the chemistry

> is not great. But that's okay. Everybody is professional. You behave like a professional and you get the work done." *(Quote 4.7 - Interviewee TUD3)*

4.1.2 RELATED KINDS OF PROXIMITY

Personal proximity affects collaborations in interaction with various other kinds of proximity. Our analyses show that *cognitive proximity* and *organizational proximity* are important criteria for academics in their selection of collaborators and, thus, these proximities affect the formation of collaborative ties and their possible output. Forty-four of the coded segments in our analysis co-occur at codes for organizational and cognitive proximity, indicating that interviewees often refer to the two dimensions in relation to one another. An illustrative segment from our interview data is presented in Quote 4.8. Note that interviewee TUE1 explicitly identifies elements of organizational proximity ("my own research agenda" and "push this research in the direction that I would like to") and cognitive proximity ("expertise complementary to mine") to drive collaborator selection:

> "What really defines collaboration is that it is because of my own research agenda. […] I can heavily use his expertise to push this research in the direction that I would like to. […] He has technical expertise that may be extremely beneficial for that project. In that sense, his expertise is complementary to mine. And it is exactly due to the complementary part that I perceive him to be an excellent partner in that project." *(Quote 4.8 - Interviewee TUE1)*

From the above case study evidence one can see that cognitive proximity is sought in potential collaborators in terms of overlap or complementarity in expertise or experience. Cognitive proximity may express in useful matches of adjacent but distinct knowledge fields (Quote 4.9), but can also exist when collaborators are from similar knowledge fields but with different orientations (Quote 4.10). This type of cognitive proximity often drives academic engagement activities, where scientists with a rather fundamental orientation engage in collaborations with their counterparts at industrial firms who have an interest in the application of technologies. As expected perfect cognitive proximity is deemed undesirable in

research collaborations, as some distance is required to be able to have something to offer to one another.

> "…there is a big overlap between our knowledge bases. He has shifted in the area of [*subfield of knowledge X*], while I shifted more in the area of [*subfield of knowledge Y*]." *(Quote 4.9 - Interviewee TUD1)*

> "I would say it has partly to do with the content. We were building certain [*high technology prototypes*] and then you are glad when somebody comes along and says he needs it. Because the [*technology*] on its own is interesting in terms of physics, but it is a little bit academic. There is always an extra satisfaction if you see that other people like what you do for non-academic reasons. For example, for potential applications and solving other types of problems that I have never thought about. So that was content-based attraction." *(Quote 4.10 - Interviewee UT3)*

Cognitive proximity includes reputation as well as experience and influence in the scientific community. The proposition that reputational standing may also be weighed when determining cognitive proximity for collaborations is confirmed in the empirical data. We see that interviewees often work with individuals of either a somewhat higher reputational standing, with the motive to benefit of this particularly experienced collaborator, or with collaborators whose reputation is not yet developed to the level of their own, in order to help these individuals to grow their career. Quote 4.11 illustrates a situation in which reputational standing affected collaborative choices, the collaborator is sought for his influence within the field.

> "In Germany it's especially with the University of [*City's name*] – it's not far away. We help each other, and the professor over there is the key person, he is the editor in chief of *[an important journal]* and has a lot of influence." *(Quote 4.11 - Interviewee UT1)*

In many cases we find evidence illustrating that too large cognitive distance will lead interviewees to avoid collaborations. Likewise, evidence suggests that too strong cognitive proximity hampers collaborations and, in some cases where cognitive proximity between individuals within the same organizations is too strong, it causes them to refrain from collaborating. For example, one interviewee (TUD2) describes that groups in his institute who

work on a particular area in nanotechnology research are unable and not willing to see potentially interesting opportunities for collaboration outside of the scope of their own area.

Organizational proximity is defined in this paper to be composed of two dimensions, namely similarity or complementarity in terms of (1) organization-specific institutions (i.e., rules, regulations, and cultural aspects) and (2) organizational objectives. Firstly, organizational proximity expresses in overlap of specific organizational institutions, it exists when individuals work for similar types of organizations. In this respect, we find that in research collaborations between university scientists the collaborators are usually organizationally proximate as they are subject to the same kind of organizational rules and regulations. For those collaborations in which university scientists get involved with collaborators at industrial firms – academic engagement activities – we do observe difficulties in establishing sufficient organizational proximity (Quote 4.12).

> "This is a European consortium. There is a consortium agreement which says that everyone is the owner of its own development, but as soon as you co-develop things then you have to agree on what you do with the results. That works very well together. It is a little bit easier in an institute like *[European consortium involving universities and public research organizations]* than with a company. Because a company is really focussed on intellectual property. Also these institutes are a little less secretive. It is a little easier to cooperate." *(Quote 4.12 - Interviewee TUE2)*

Alternatively, organizational proximity also drives research collaborations when individuals strive to attain closely related objectives, either similar goals or goals that are complementary in nature. Collaboration is described by many interviewees as a means to an end, which indicates that it is a vehicle for the partners to achieve certain goals. Often, organizational proximity in terms of complementary goals is related to the existence of cognitive proximity. In Quote 4.13 cognitive proximity helps by combining knowledge about "special materials" and knowledge about "tools" which creates "options" for both collaborator partners to attain a "rather special" goal. Interviewee UT2 is very explicit about the need for collaborations to create added-value for both parties (Quote 4.14).

> "We were enthusiastic about the options on both sides. […] He grows things that not many people in the world grow, so he makes special materials. I have a special tool. So together we can do something that is, again, rather special." *(Quote 4.13 - Interviewee TUE3)*

> "What is very important is that should also realize that there should be added-value for both sides. You cannot start collaboration only out of your interest, it won't work. So you have to realize what the added-value is for the other." *(Quote 4.14 - Interviewee UT2)*

Our results put *social proximity* in a new perspective. We find that its role is to create an opportunity for the assessment of one's personal proximity to potential collaborators. Numerous times our interviewees describe encounters with socially proximate individuals as the setting in which they were able to determine whether another party was personally close to them. Social proximity has no direct effect on collaboration choices and output, but serves as a mechanism to assess, develop and maintain personal proximity that can be crucial in collaborations. In the interview segment below knowing being familiar with an individual on the personal level is related directly to professional relationships – through conferences – that make for social proximity.

> "Knowing the person personally well plays an important role, although not always. Professional relationships, people you meet in conferences continually and you discover that you have common interests, expertise that are complementary so that you can do more together than you could do separately and then one thing leads to another. Then you start doing collaborative research. It has never occurred to me: "Hey, I have an idea and I need a chemist, I have got to go and find a chemist!" That has never happened to me. […] Maybe it is interaction with the people which stimulates me to think of collaborative projects and then I know immediately who the person is going to be." *(Quote 4.15 - Interviewee TUD3)*

In a similar fashion, our evidence indicates that social proximity not only enables one to determine the extent of personal proximity to potential collaborators, but also aids in the assessment and exploration of cognitive and organizational proximity.

Considering the influence exerted on collaborations by institutional proximity, the evidence is mixed. Collaborators do not attribute any effects to distance in terms of informal rules and regulations prevalent in specific territories, such as norms and values that are imposed by national identities and cultural backgrounds. When there is institutional distance it can easily be overcome without any implications for the collaborative process (Quote 4.16 and 4.17).

> "No, because I have had several courses and I have made a book for myself. And I had courses in doing business with the French. No, I can deal with that." *(Quote 4.16 - Interviewee UT1)*

> "I think it will never cross my mind to reconsider collaborations on the basis of cultural differences. I cannot imagine I would do that. On the contrary, I find it very natural in our work, we have an international network. I like cultural differences actually, I find them very interesting, we learn from each other. […] And also here, at this university, the number of PhD students that we are coaching ranges over huge cultural backgrounds. As coaches we are forced to cope with big cultural differences. […] It's not, let's say, an enabler for collaborations but it certainly is not a disabler, it does not really matter." *(Quote 4.17 - Interviewee TUE1)*

Although distance in terms of more informal institutions such as norms, values, and other culture-specific elements between collaborators from different administrative geographical entities does not appear to hinder research collaborations per se, formal rules and regulations of different geographical entities can in fact pose an obstacle. Section 2 discussed how differences in intellectual property rights regulations and conditions set by specific research funding programmes could create significant institutional distance between collaborators. The empirical evidence supports this. Despite constraints on institutional proximity between different nations, regions and cities, not all forms of collaboration are ruled out. For example, interviewee UT3 explains how formal research collaborations with his German acquaintance are often precluded, but mutually beneficial informal collaborations can still take place because they are not competitors for funding on the national level (Quote 4.18).

> "The type of work that we do is basically the same, but here we have a very fortunate situation that we are not really direct competitors, because

> we sit in different countries. So when he applies for money for a research project or so, that doesn't bother me. Actually I like it. He can tell me about new ideas. We can really exchange also secret ideas even if we are competitors. Because we go for different types of funding. […] Currently we are doing theoretical projects that are not funded but we work on it and then publish something. […] and he can use our computer facilities, our university doesn't know that. […] Since we are in similar positions but not competitors or connected I can freely offer him my advice. It's totally independent fresh advice." *(Quote 4.18 - Interviewee UT3)*

Finally, interviewees agree that geographical proximity eases research collaborations, it is simply more pragmatic to be able to have face-to-face interactions when necessary. Collaborations with partners at arm's length distance have a higher intensity. However, geographical proximity is often not a motive to collaborate with one partner instead of the other. Rather, cognitive and organizational proximity overrule the argument of the convenience of being in each other's close proximity. Sufficient cognitive proximity is argued to be available mostly outside The Netherlands, at least in our context of nanotechnology research. During each interview the interviewees were asked to list names and locations for collaborators of their choice. This exercise yielded a diverse set of countries, including various countries at great geographical distance, in which collaborators operated (e.g. Japan, Germany, Belgium, the United Kingdom, Russia, Italy, Canada, Spain and Chile). Geographical distance can be overcome when personal proximity exists (Quote 4.19).

> "I think you can do a lot without daily contact and without being physically together, but before that you have to have one-to-one contact. That's what my idea is." *(Quote 4.19 - Interviewee UT1)*

4.2 PERSONAL PROXIMITY: CONTRIBUTIONS TO THEORY

Based on our qualitative evidence we propose the model depicted in Figure 1 to represent the role different proximities have in shaping research collaborations and affecting their output. We find that there is ample evidence to suggest that personal proximity affects collaborative choices and outputs. Personal proximity and the resulting 'clicks' moderate the

relationship between organizational and cognitive proximity and collaborator selection and collaboration performance. Organizational and cognitive proximity are dimensions that guide collaborators' choices regarding the formation of research collaborations. In other words, complementarity in terms of organizational settings, organizational goals and cognitive inputs is a motivation for collaborations. However, 'clicks' that develop under conditions of personal proximity may reinforce the perceived need to collaborate or, when personal proximity is lacking, prevent collaborations from being established. Personal proximity evolves over time, as partners get to know each other while working together. Hence, its impact is not limited to the formation of research collaborations, but extends to actual output of the collaboration and decisions regarding continuation. Social proximity is an antecedent to personal, cognitive and organizational proximity, as it enables to explore those forms of proximity. Institutional distance can affect the formation of formal collaborative ties negatively, but at the same time opens opportunities for the formation of interesting informal research collaborations. The well-established role of geographic proximity is confirmed in this study.

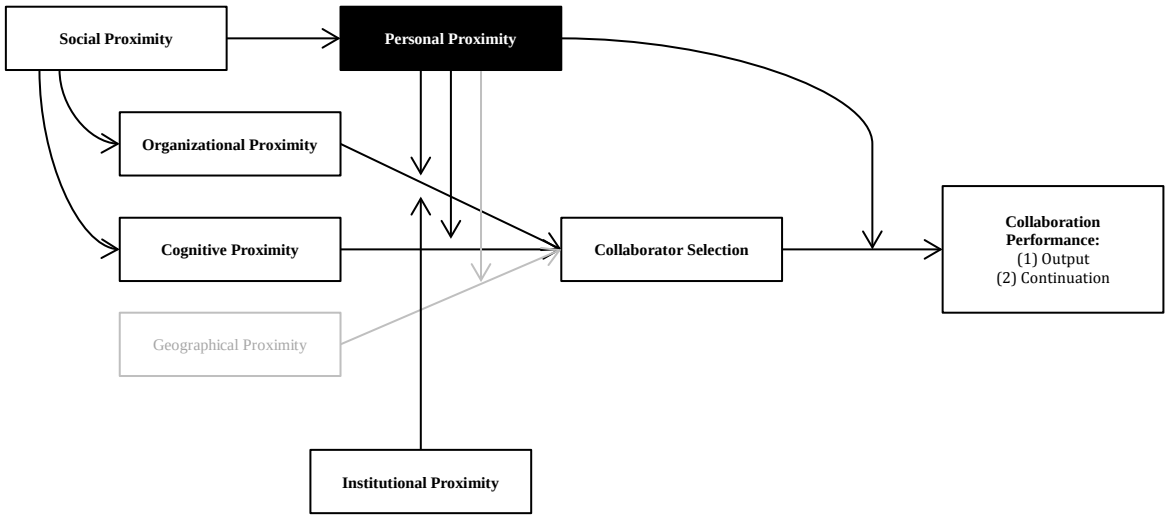

Figure 1 – Personal Proximity its Role in Research Collaborations

The rich empirical data enables us to further refine and demarcate earlier theorization of the concept of personal proximity (e.g. Caniëls et al., forthcoming). We wish to disentangle the concept of 'personal proximity' from the idea of 'clicks', as the two were used interchangeably but do not actually cover exactly the same content. Personal proximity expresses purely in similarity between collaborators regarding personality traits and characteristics and the associated behavioural patterns. The 'click' is a result of personal proximity. In other words, it may be seen as the 'sweet spot' on the continuum of personal

proximity. Whereas earlier definitions of personal proximity also refer to the extent to which collaborators enjoy each other's company (notably Caniëls et al., forthcoming), we feel that this is actually an indication of the resultant click. The empirical material offers many contributions to the understanding of clicks. TUD3 (Quote 4.1) captured it well by describing the most prosperous collaborations as involving 'clicks' with people whom he "knows, trusts and respects." This corresponds closely to the definition of clicks given in Caniëls et al. (forthcoming, p.8): "a mutual feeling of acceptance, appreciation and interest in each other's ideas." In terms of the homophily-principle (McPherson et al., 2001, p.415), personal proximity is expressed through "similarity" and the click is the "connection bred" as a result thereof.

5. CONCLUSIONS

Our exploration of the role of personal proximity, relative to other dimensions of proximity, in Dutch nanotechnology research collaborations has several theoretical implications. The rich interview data shows that personal proximity can either enhance the positive effects exerted by other proximities or impede collaborations despite sufficient proximity on other dimensions. Clearly, the formation of research collaborations is motivated primarily by identification of optimal cognitive and organizational proximity between potential collaborators. Research collaborations are driven by (individual or organizational) goals and these can be realized only when an optimal cognitive complementarity between collaborators exists. Nevertheless, one should not underestimate the role of personal proximity. 'Clicking' of collaborators on the personal level smoothens the collaborative processes, thereby enabling collaborators to better exploit opportunities created by their cognitive and organizational proximity. Eventually, the 'click' also affects the performance of research collaborations. Actual clicks may lead to higher quality output and continuation of the collaboration, whereas a lack of clicks can be detrimental to output and may lead to termination of the collaboration. Social proximity serves as a vehicle to explore, assess, and develop personal proximity between collaborators. The optimal degree of institutional proximity is variable, and depends on whether the goal requires informal or formal collaborative activities. Effects of geographical proximity are often overruled by the existence

of cognitive and organizational proximity. Additionally, a lack of geographical proximity can be compensated for when collaborators are personally close.

In line with the tentative argument made in Caniëls et al. (forthcoming), the core theoretical implication of this study is that personal proximity, a dimension of proximity that – unlike the other dimensions – is endogenous to the individual agent, affects collaboration and innovation. Previous studies have followed conceptualizations of proximity that either disregard of the personal dimension (e.g. Boschma, 2005) or conflate the concept with social proximity (e.g. Knoben and Oerlemans, 2006). We show that personal proximity affects collaborative choices and processes in nanotechnology research. Hence, conceptualizations of the proximity concept should include personal proximity as a distinct dimension. Future theoretical and empirical research should take into account personal proximity and explicitly measure its impact on collaborations, as it is too limited to assume that personal closeness is derived from embeddedness in social networks, just as social proximity. Social proximity is an exogenous factor in research collaborations, while personal proximity is endogenous to the individuals in the collaboration.

Our findings on personal and related kinds of proximity are relevant beyond particular collaborations involving an academic partner in Dutch nanotechnology. This leads to at least three avenues for further research. The first one is related to open innovation, i.e. "… the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation..." (Chesbrough, 2006, p. 1). Open innovation heavily depends on collaboration between individuals (Huizingh, 2011). In particular, open innovation strategies require various organizational modes involving extensive collaboration, such as alliances and various forms of contract research (e.g. Bianchi et al., 2011; Wright et al., 2008). It would be worthwhile to investigate the role of personal proximity in the setting of open innovation. Open innovation usually requires substantial trust between partners which may be facilitated be personal proximity.

Second, understanding the role of personal proximity is a first step towards explaining dynamics at higher levels than just that of individual dyadic relationships as it influences what types of research collaborations develop over time between academics and their peers in science or industry. This raises the question as to whether it is possible to partially explain the evolution of network structures and regional paths of development by personal proximity. It

would be an interesting line of further study to increase our understanding of the role of personal factors in the development and growth of networks.

Third, personal proximity's role is not necessarily limited to collaborations of academic or industry partners only. It may also be important in policy making processes. In particular, university or industry researchers who are personally close to policy makers may more easily see their output reflected in policy making processes. The dimension of personal proximity affects the extent to which individual agents are able to shape processes of creating and transferring knowledge and innovation, either intentionally or unintentionally. These dynamics are a potential field of interest for collaboration researchers.

Further recommendations for future research come forth from our research design. The results of this study are based on a limited number of interviews with top Dutch nanotechnology researchers. It would be interesting to study how different dimensions of proximity affect dynamics in research collaborations of more junior researchers and researchers in different network positions (i.e., researchers who are not in the largest connected component or researchers at the global top or bottom in terms of centrality). We suggest that more central researchers are most likely best able to 'use' personal and other kinds of proximity in their relationships to full effect.

Ultimately, personal proximity affects the performance of research collaborations. If the partners are personally close they tend to work together for more than one project, while partners who are not personally close tend to terminate collaborations. In the latter cases the investment in the collaboration and the knowledge created in the collaboration is partly lost. Therefore, not only scholars themselves but also university management and research policy makers have a vested interest in taking personal proximity into account. While the individual may be more cautious with collaborations lacking sufficient personal proximity, management and policy may want to invest in trainings to enable scholars working together with people less like themselves. A diversity policy including scholars differing in ethnical background, gender and age would also help supporting personal proximity between diverse kinds of scholars.

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Appendix A – Interviewees' Centrality in the Global Nanotechnology Research Network

Interviewee	Eigenvector Centrality	Closeness Centrality	Degree Centrality	Eccentricity
TUD1	-	-	-	-
TUE1	-	-	-	-
UT1	-	-	-	-
TUD2	$3.76*10^{-7}$	0.17	$6.07*10^{-5}$	14
TUE2	$6.75*10^{-6}$	0.19	$1.71*10^{-4}$	13
UT2	$6.03*10^{-7}$	0.17	$1.12*10^{-4}$	14
TUD3	$1.29*10^{-10}$	0.13	$7.36*10^{-6}$	16
TUE3	$2.63*10^{-6}$	0.19	$1.55*10^{-4}$	15
UT3	$2.36*10^{-5}$	0.17	$5.89*10^{-5}$	14

Appendix B – Most Influential Researchers in the Global Nanotechnology Research Network*

Location	Eigenvector Centrality	Closeness Centrality	Degree Centrality	Eccentricity
United States	0.11180	0.18	$5.15*10^{-4}$	15
Germany	0.10930	0.18	$4.53*10^{-4}$	15
United States	0.10790	0.18	$4.56*10^{-4}$	15
Germany	0.10611	0.18	$4.10*10^{-4}$	15
Germany	0.10609	0.18	$4.08*10^{-4}$	15

**: according to eigenvector centrality.*

Appendix C – Least Influential Researchers in the Global Nanotechnology Research Network*

Location	Eigenvector Centrality	Closeness Centrality	Degree Centrality	Eccentricity
China	$8.92*10^{-17}$	0.073	$1.84*10^{-6}$	22
Malaysia	$2.12*10^{-16}$	0.069	$3.68*10^{-6}$	22
Malaysia	$2.13*10^{-16}$	0.069	$3.68*10^{-6}$	22
India	$2.52*10^{-16}$	0.081	$1.84*10^{-6}$	20
Russia	$4.19*10^{-16}$	0.080	$5.52*10^{-6}$	21

**: according to eigenvector centrality.*