Knowledge networks and strong tie creation: the role of relative network position

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Abstract

The proximity literature usually treats proximity in terms of common attributes shared by agents, disregarding the relative position of an actor inside the network. This paper discusses the importance of such dimension of proximity, labelled as in-network proximity, and proposes an empirical measurement for it, assessing its impact (jointly with other dimensions of proximity) on the creation of strong knowledge network ties in ICT in the region of Trentino. The findings show that actors with higher in-network proximity are more attractive for both other central actors and peripheral ones, which is further strengthening their position within the network. In detail, the centrally positioned actors repeat collaboration with other central actors in the network, as central actors gather more ‘reputation’, signalling that they will possess the needed knowledge resources. Relatively peripheral actors, either new or not so active inside the network, seek for collaboration with relatively central actors in order to tap on knowledge resources they do not acquire.

Keywords Knowledge networks · In-network proximity · Strong ties · Proximity dimensions

JEL Classification C33 · D85 · L14 · R11 · R12

1 Introduction

The significant role of knowledge and knowledge networks in the innovation process is central in the literature on regional development. Regions create and use knowledge to build competitive advantage (Asheim et al. 2007). Knowledge

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networks operate as channels for knowledge creation and transfer (Owen-Smith and Powell 2004; Boschma and ter Wal 2007), through social and business links (Granovetter 1973). These relationships can be more or less intense (Granovetter 1973).

A key issue in the literature of knowledge networks is how agents choose other agents for the creation and transfer of knowledge. The literature acknowledges that this happens because of similarities in the attributes of the actors which are referred to as homophily in the sociology literature (Borgatti and Foster 2003), or proximity in the economic geography literature (Boschma 2005). The proximity literature has produced several classifications of proximity (Torre and Rallet 2005; Boschma 2005; Broekel and Boschma 2012; Caragliu and Nijkamp 2016). The common feature of these taxonomies is that they consider the similarities in the attributes of the actors, but they disregard their relative position within the network.

The relative position of an actor within the network, however, seems to be important for the creation of strong ties between actors that are beneficial for the actors in order to face uncertain situations (Rost 2011; Crescenzi et al. 2016). Actors are likely to seek to create strong collaborative ties with other more central actors in the knowledge network, than with more peripheral ones. This is because the relatively more central actors are associated with a higher number of connections and, consequently, an easier reach to knowledge resources.

The aim of this paper is to define a new measure of proximity, the in-network proximity, able to cover this gap in the literature. Apart from the conceptual justification and definition of this kind of proximity, the paper will also propose an empirical measurement, examining how it affects the probability of repeated collaborations (strong ties) between actors.

This study places itself within the literature on core-periphery network structure (Morrison and Rabellotti 2009) and on the effect of proximity on knowledge networks that take into consideration the centrality of actors inside the network (Autant-Bernard et al. 2007; Cassi and Plunket 2015). However, compared with the existing empirical studies that use the absolute difference of centralities of actors inside the network, this paper contributes with an analytical method of assessing whether two actors can be considered central or peripheral, and simultaneously distant or proximate between them.

For doing so, we use the quantiles of the absolute differences and the sums of all pairs of actors inside the knowledge network. Empirically, we assess the impact of in-network proximity, alongside other kinds of proximity on the occurrence of repeated research collaborations based on a unique set of data on collaborative projects in Information and Communication Technologies (ICT) in the Italian region of Trentino.

The paper is structured as follows. Section 2 presents a critical review of the literature on the different dimensions of proximity, pointing out the relevance of the relative distance between actors within a network. Section 3 provides a definition and a measurement for in-network proximity. Section 4 presents the data of the case study analysis, in which the role of in-network proximity on networks' development is tested. Section 5 presents the results of the analysis, and Sect. 6 discusses the conclusions and the implications out of the findings of the study.

2 Knowledge networks and the importance of actors' proximity

The literature confirms that the similarity in the characteristics of actors (proximity) is important for the development and reinforcement of collaboration between them (Boschma 2005; Boschma and Frenken 2010; Balland et al. 2015; Fitjar et al. 2016). However, proximity means more than just geographical closeness: two actors in a knowledge network can demonstrate proximity although they are not geographically close. Several works provided different classifications of proximity (Torre and Rallet 2005; Boschma 2005; Broekel and Boschma 2012; Caragliu and Nijkamp 2016). The most used classification is the one by Boschma (2005) who proposed five dimensions of proximity that affect the propensity of actors to exchange knowledge and innovate. These dimensions are geographical, cognitive, organizational, social, and institutional proximities.

Geographical proximity is represented by the physical distance of two actors and is regarded beneficial for knowledge transfer. In the empirical studies, the geographical proximity is measured by the absolute geographical distance between two actors (Broekel and Boschma 2012), travel time (Ejermo and Karlsson 2006; Lenzi and Perucca 2020), or by categories of geographical proximate actors, like inside the country, neighbouring countries and the rest of the world (Ponds et al. 2007; Hansen 2015), or just local and non-local (Boschma and ter Wal 2007).

Cognitive proximity expresses the overlapping in knowledge bases of actors. To measure cognitive proximity, empirical studies use proxies such as technological profiles derived from patent data (Nooteboom et al. 2007), statistical classifications of economic activities, like NACE codes (Broekel and Boschma 2012; Broekel 2015), or industrial classification with digits (Boschma et al. 2009, 2012).

Organizational proximity concerns the degree of similarity of actors in organizational terms. Organizational proximity is assumed to help the knowledge exchange and reduce the transaction costs. Empirically, there is a distinction between profit and non-profit organizations, or private and public (Cantner and Graf 2006; Broekel and Boschma 2012). Alternatively, the organizational proximity can be measured in terms of subsidiaries of the same parent organization (Balland 2012; Balland et al. 2015; Broekel 2015).

Social proximity refers to the embeddedness of actors in the micro-level, in terms of friendship, kinship, and experience (Boschma 2005). The majority of the empirical literature tends to consider the idea of social proximity equivalent to the concept of strong ties (Broekel 2015). Alternatively, in the empirical literature, social proximity is treated as the possibility of two actors to be close socially after sharing a common situation back in time (Broekel and Boschma 2012) or the degree that individuals affiliated to the organizations under research are socially interacting between them out of the organizational context (Huber 2012).

Finally, institutional proximity is an aspect of proximity where the actors share common institutional and cultural attributes (Gertler 2003; Capello et al. 2009).

Institutional proximity provides to the actors stable conditions for knowledge transfer (Boschma and Frenken 2010). It can be expressed by either formal institutions, such as laws, or informal institutions, such as cultural norms, which affect the way in which actors coordinate their actions.

The common characteristic of all the aforementioned dimensions of proximity is that they take into consideration the attributes (characteristics, values) that individual actors may share. They disregard the relative position of an actor inside the network, and in this case inside the knowledge network. This element, however, can be assumed to be extremely relevant for the occurrence of strong ties. This idea stems from the theory of preferential attachment, which supports that the most connected (central) nodes are more probable to receive new links (Barabasi and Albert 1999).

Since the actors become part of the network, they increase their connectivity according to how much they are suitable to compete for connections (Bianconi and Barabasi 2001). In this way, the fitter nodes outcompete the less fit ones. So, when a new actor enters into the social network, it seeks to be connected with centrally positioned, well-established actors (Newman 2001; Wagner and Leydesdorff 2005). Hence, there is a cumulative advantage for the better positioned actors (Gluckler 2007). Future ties tend to form around strong ties by processes of trust and indirect referrals. In this way, persistent and resilient network structures emerge within tightly connected groups of actors. Simultaneously, the networks tend to expand through a process in which the actors seek for diversity of relations (Gluckler 2007; Morrison and Rabellotti 2009).

Based on preferential attachment (Barabasi and Albert 1999), literature has considered the position of the actors in terms of actor's and tie's attributes and in structural way (brokerage and bridging ties, triadic closure). The idea of brokerage and bridging ties is connected to the Granovetter's (1973) strength of weak ties. Bridging is the activity in which a tie connects separate sub-networks inside the main network (Everett and Valente 2016). Bridging ties enable actors to tap on resources that otherwise, they would not be able to have access to, and the control of such ties may empower actors inside the network (Cassi and Plunket 2015; Everett and Valente 2016). This control of an actor over a bridging tie is defined as brokerage (Burt 2005; Everett and Valente 2016). Hence, brokerage is treated as a node attribute and highlights the importance of the position of an actor inside the network.

Again, originating to Granovetter (1973) and closely connected to the notion of brokerage (Burt 2005), another measure that underlines the importance of an actor's position inside the network is the triadic closure. Triadic closure is the case when a node acts as an intermediary, connecting two other actors, translated in a social context as 'a person introducing two of its personal acquaintances to each other' (Opsahl 2013; ter Wal 2013). Therefore, in case that two actors are not connected with each other, the actor that is a common connection holds, in one hand, a favourable position, which though requires effort in preserving two separate relationships, and these two separate actors are more probably to connect with each other (ter Wal 2013). Triadic closure is frequently used by the literature as a structural measurement of the 'status' or 'reputation' of an actor inside the network (Balland et al. 2016).

In line with strong and weak ties (Granovetter 1973), we assume that actors which have 'privileged' positions (in terms of bridging, triadic closure, or in our

case centrality) inside the network, to know and trust each other, so they are preferred for collaboration. However, their knowledge may overlap; therefore, bearers of new knowledge may be more peripheral or new actors in the network.

3 In-network proximity: a definition and a measurement

3.1 In-network proximity: a definition

There had been attempts to measure the relative position of actors inside the network, taking into consideration this core-periphery structure of social networks (Morrison and Rabellotti 2009). Existing studies address the relative position of actors inside the network, using the absolute difference of actors' centrality inside the network (Autant-Bernard et al. 2007; Cassi and Plunket 2015). The absolute difference of the centrality of two actors indicates only the relative distance of two actors' positions inside knowledge networks, but not their relative position proximity. Also, a small absolute difference does not indicate the influence that an actor has in the network, i.e. small absolute difference in centrality may exist between two actors that are both central and between two actors that are both peripheral. This paper introduces the concept of in-network proximity, defining it in terms of the position of the actor inside the network in respect with the rest of the actors. In other words, in-network proximity measures how central the actor is in the network, compared with the centrality of other actors. In case that two actors are in-network proximate, this means that they have similar central or peripheral positions in the network, while if they are in-network distant, the one is more central and the other more peripheral.

A necessary premise to the definition of in-network distance concerns the interpretation of proximity. In fact, actors can be in-network proximate or distant in more than one way. An actor can be considered more central in relation with the rest of the agents of the network in terms of the number of connections that it has (*degree centrality*) (Freeman 1978). *Betweenness centrality* (Freeman 1977) describes the role of an actor in connecting two different parts of a network. In social networks, this role represents the ability of the actor to allow information to pass from one part of the network to another. *Closeness centrality* (Freeman 1978) constitutes another way to measure the importance of an actor inside the network. It indicates how close this actor is to all the other actors of the network. Finally, *eigenvector centrality* constitutes a measure for the influence of the actor to the rest of the network (Newman 2008), taking into account the importance of the agents connected to this actor.

As the centrality of the actors can be assessed by different points of view, the relative position of an actor considering its centrality inside the knowledge network may have differentiated meaning (Broekel and Boschma 2012; Cassi and Plunket 2015). Although the meaning of each centrality measure is important in understanding the role of an actor inside the network, the measure of eigenvector centrality offers a more sophisticated view of an actor's influence. An actor with few connections may play a more important role in the network if those few connections are with very well-connected other actors (Hansen et al. 2011; Golbeck

2013). Therefore, we address centrality in eigenvector terms, assuming that this measure of centrality offers a more objective description of the actors' connectivity inside the network, taking into consideration the importance of the actors' connections.

Thus, central actors, (in our case in terms of eigenvector centrality), that are better in-network positioned are expected to be more preferred for repeating collaboration, either by peripheral or by other central actors. This leads us to distinguish three cases: two actors can be either central and proximate, or peripheral and proximate, or in-network distant and this is assumed to have a different impact on the occurrence of repeated collaborations. More precisely, the in-network proximity is expected to be relevant in two specific circumstances, leading to two different research hypotheses:

H1a In-network proximity between two central actors affects positively the repeated collaborations (strong ties) between them.

H1b In-network distance between two actors affects positively the repeated collaborations (strong ties) between central and peripheral actors.

The proximity literature has focused extensively on the substitution and overlap between spatial and non-spatial forms of proximity (i.e. geographical proximity and the rest proximity dimensions) (Broekel and Mueller 2018; Fitjar et al. 2016; Hansen 2015; Kuttim 2016). Hansen (2015) refers extensively to substitution and overlap effects between geographical proximity and the rest non-spatial proximity dimensions. The substitution effect is the case where non-spatial dimensions of proximity replace the absence of geographical proximity (distant actors) in the tie creation. The overlap effect is the case where geographical proximity facilitates the effect of non-spatial forms of proximity. In other words, there are cases where geographical proximity intensifies the effect of another type of non-spatial form of proximity on the tie creation. However, the literature gives little attention to the potential substitution and overlap between different dimensions of non-spatial proximity. Few recent studies (Werker et al. 2019; Janssen et al. 2020) deal with these effects between non-spatial proximity dimensions, however, they lean towards focusing on cases of substitution effect.

Drawing insights from the literature on proximity dimension substitution and overlap, we assess these effect on the new measure of in-network proximity. On one hand, the collaboration between two actors that are in-network proximate will be intensified if these two actors share also other common characteristics. This signifies an overlap effect between in-network proximity and the rest proximity dimensions. On the other hand, it is a fact that new actors enter the network and create linkages with established actors. The creation of a tie between in-network distant actors, happens through other common attributes of these actors, indicating a substitution effect between in-network proximity and other proximity dimensions. Therefore, in-network proximity is expected to both overlap and be substituted by other proximity dimensions, leading to the following hypotheses:

H2a Geographical proximity overlaps and/or substitutes in-network proximity.

H2b Institutional proximity overlaps and/or substitutes in-network proximity.

H2c Organizational proximity overlaps and/or substitutes in-network proximity.

3.2 In-network proximity: the measurement

For measuring in-network proximity, it is necessary to assess two elements: the position of the single actor inside the knowledge network, and the distance of its position from the position of the rest of the actors inside the network (proximity). In terms of proximity, we identify the case that two actors are distant, which implies simultaneously that one is relatively positioned more centrally than the second, and the case that two actors are proximate. In terms of position in the network, these two actors can be either both relatively central (proximate), or both relatively peripheral (proximate). Therefore, we can distinguish the following three cases:

$$\text{A pair of actors can be } \begin{cases} \text{in-network distant} \\ \text{in-network proximate} \end{cases} \begin{cases} \text{both central} \\ \text{both peripheral} \end{cases} \quad (1)$$

For every pair, two actors for being proximate, they need to have a relatively low absolute difference of their centrality scores, while for being central they need to have a relatively high sum of their centrality scores, which means that they have to be below or above certain thresholds. In order to set the lower (L) and upper (U) threshold for this study, we use the quartiles ($Q[25]$ and $Q[75]$) of the distributions of absolute differences, and centrality scores, respectively.¹

Estimating the distribution of the absolute differences of all the pairs of actors the lower threshold is $L = Q[25]$ and the lower adjacent value is defined as x_i , such that $x_i \geq L$, and $x_{(i-1)} < L$. Therefore, an absolute difference between two actors can be characterized relatively low, if $\text{absdif}_{ij} < L$. On the other hand, centrality score constitutes an actor attribute that has to be expressed in a dyadic way. For an actor to be characterized relatively central or not, we estimate the distribution of the centrality scores of all the actors in the knowledge network. The upper threshold, in this case, is $U = Q[75]$ and the upper adjacent value is defined as x_i , such that $x_i \leq U$, and $x_{(i+1)} > U$. The centrality score of an actor should be $x_i > U$, for the actor to be considered relatively central. For every pair of actors in the knowledge network, both of

¹ The quartiles of the distribution are selected as moderate thresholds. Alternatively, different percentiles could (2%, 9%, 91% and 98%), or even the outliers could be used for defining stricter conditions of proximity and centrality. In this latter case, the lower threshold is $L = x[25] - \frac{3}{2}(x[75] - x[25])$ and the upper threshold is $U = x[75] + \frac{3}{2}(x[75] - x[25])$. The empirical analysis was tested with different percentiles and the results were robust, strengthened when the percentiles were used and weakening when the percentiles were increased.

them are considered central if the sum of their centrality scores is higher than $2U$. Thus, a pair of actors is characterized central, if $\text{sum}_{ij} > 2U$.

Summing up, two actors are in-network proximate and both centrally when they have relatively low absolute difference and relatively high sum of their centralities. They are in-network proximate and both peripherally positioned, when they have relatively low absolute difference and relatively low sum in their centralities. They are in-network distant in any other case.

4 The empirical case

4.1 The region of Trentino (Italy)

The present research analyses the network of actors participating in collaborative projects in the ICT regional innovation system of Trentino in Italy. The region of Trentino has some unique characteristics regarding its geography, history and funding policy. Geographically, Trentino is located in the passage that connects Italy with Austria and further with Germany. Due to its location, it is linked to both German and Mediterranean markets. Historically, Trentino has been an agricultural region with “soft” industrialization during the 1960s and 1970s. Although agriculture has still strategic importance for the provincial economy, the last 20 years Trentino had an impressive growth in the number of businesses in the ICT sector. Finally, the region is an Autonomous Province, enjoying considerable autonomy from the Italian central government and has its own elected government and legislative assembly. The province is in control of 9/10 of the taxes collected in its territory. During the last two decades, the province of Trento has invested heavily in the ICT sector, with the purpose of making Trentino a key technology hub in Central Europe.

4.2 Data from R&D projects

The data source most used in the literature to trace knowledge transfer depicted in knowledge network form is the patent data (Cantner and Graf 2006). However, in the ICT field, there is not a lot of patenting activity, while when it exists the quality of these patent is difficult to be assessed, making the use of patent data in several cases quite problematic.

In this paper, we use data on R&D collaborative projects on ICT sector that include at least one actor located in Trentino. It is a complete primary dataset, that includes the entire population of projects, and consequently of the actors that participated in such project for a period of 15 years (2000–2014). There are two R&D projects before 2000, however, they are not taken into consideration, as the Autonomous Province of Trento started investing heavily on ICT research and development since 2000. We collected the entire population of projects (regionally, nationally, internationally, publicly or privately funded) using the following procedure. The complete list of public and private organizations with activity on the ICT sector was retrieved by the official website of the regional authority. For every organization in this list,

we visited their official websites, where they publish their R&D activity. We cross-checked the projects collected with this method, as well as, the list of organizations, in the web catalogues of research projects of European Commission (CORDIS), the Autonomous Province of Trento, and smaller public and private funders.

Data on R&D projects include information at the level of organizations, like the title, acronym and abstract of the project, start and concluding dates, funding source, list of participants and coordinating actor. For every participant and coordinator, all projects include location and type of organization. In Trentino, for the period from 2000 until 2014, a total number of 2,394 actors were identified, participating in 543 ICT R&D projects. The average duration of the projects is 3.6 years.

From these actors, 6.55 per cent (157 actors) is located in Trentino, 15.29 per cent (366 actors) is located in other regions of Italy, and the rest 78.15 per cent (1,871 actors, the biggest part of the actors) is located in other countries. Additionally, there is a detailed distinction of actors in terms of incentives and orientation of organization. The actors are distinguished in universities, research centres, large firms, SMEs, public agencies, and other kinds of organizations. So, 20.12 per cent (481 actors) of the actors is universities, 23.16 per cent (555 actors) concerns research centres, 19.57 per cent (468 actors) is large firms, 25.08 per cent (601 actors) is SMEs, 7.26 per cent (174 actors) is public agencies, and the rest 4.8 per cent (115 actors) concerns other kinds of organizations.

4.3 Multiplexity of networks and regression

Networks are multiplex entities, with a variety of agents connected between them in a variety of relationships (Lazega and Pattison 1999; Skvoretz and Agneessens 2007). This happens as the actors interact in different social contexts that overlap in an extent. Therefore, the constellation of the actors participating in ICT R&D projects in Trentino can be connected between them with different relationships indicating knowledge transfer. The collected data provide this type of information on collaboration, coordination and funding of projects, indicating interaction with an actor that plays a specific role inside the knowledge network.

The aforementioned kinds of relationships (collaboration, coordination, and funding) can be traced for all the R&D ICT projects in Trentino and indicate knowledge transfer between actors. The main relationships are the collaboration between two actors. It is implied by the common partnership of two actors in the same R&D project. The assumption here is that knowledge flows without restrictions among the partners of every project, and consequently partnership in the same projects implies information sharing (Inkpen and Tsang 2005; Assimakopoulos et al. 2016; Tsouri 2019).

Other two kinds of relationships indicating knowledge transfer were extracted by the data, being significant for the existence and management of the knowledge creation and transfer in every project. The first is the relationship of coordination. It comes from the interaction of a project participant directly with the coordinating agent of the project. The role of a coordinator is to distribute and collect the knowledge produced by the project. Therefore, the coordination relationship

Table 1 Descriptive knowledge network measurements of Trentino ICT Collaboration, Coordination, and Funding Networks (2000–2014)

	Collaboration Network (2000–2014)	Coordination Network (2000–2014)	Funding Network (2000–2014)
Nodes	2394	2394	2394
Edges	46,148	4090	2717
Average degree	43.277	3.831	2.101
Network diameter	4	7	7
Graph density	0.016	0.001	0.001
Network centralization	0.380	0.083	0.895
Average clustering coefficient	0.872	0.274	0.024
Average shortest path length	2.536	3.917	2.385

The statistical analysis was performed with Gephi (Bastian et al. 2009) and UCInet (Borgatti et al. 2002)

appears important for the diffusion and the management of knowledge inside the network (Fritsch and Kauffeld-Monz 2010; Phelps et al. 2012). The second relationship identified is the funding relationship, which is important for the existence of the project itself and, as a result, for the transfer of the knowledge among the participants (Landry et al. 2007). Simultaneously with the flows of funds from the funding entities to the participants, these funding entities act like knowledge pools and requiring knowledge back in the form of reports.

Data on these three kinds of relationships, namely collaboration, coordination and funding, collected for the Trentino ICT sector, in combination with the agent characteristics (e.g. location, organizational kind), can be depicted in three different networks (collaboration, coordination, and funding), used to empirically verify the hypotheses H1 and H2. Descriptive evidence for the cumulative knowledge transfer by the three different types of relationships in the period 2000 up to 2014 is presented in Table 1. The collaboration network demonstrates small world properties. These properties allow fast access to the most peripheral actors of the network. The coordination network appears to be less centralized than the other two networks. This implies the existence of few high degree actors inside the network that are connected with a high number of low-degree actors, reflecting the accumulation and management of knowledge by certain actors in the knowledge network. In contrast, the funding network is highly centralized, implying the existence of a dominant big funding agency and a range of other much smaller funders (Table 1).

The data of the Trentino ICT R&D projects can be summarized in three one-mode sociomatrices (actor x actor), portraying the three different networks resulting from the collaboration, coordination and funding relationships. The result is three square matrices with rows and columns the number of actors, depicting actor-to-actor interactions. In addition, the characteristic of the agents is expressed in the same, dyadic, way, resulting to square matrices of the same size with the rest of the variables.

The level of analysis is the tie, i.e. link between two actors. The linear model that represents the interactions between the matrices/variables cannot be estimated by with the standard statistical and econometric methods, due to the presence of structural autocorrelation in this type of relational data. The observations are not independent, since they are interactions between the same actors in the network. To avoid this problem, we use Quadratic Assignment Procedure (QAP), a permutation method that makes no assumptions about the distribution of the parameters (Cantner and Graf 2006; Maggioni et al. 2011; Graf and Kruger 2011; Broekel and Boschma 2012; Cantner and Rake 2014; Tsouri 2019). It creates a permutation distribution that could have been produced by random datasets, with the same structure but different node assignments as the initial dataset, permuting the rows and columns of the dependent variable. Therefore, the p value produced is the frequency of the coefficients of the permuted dataset compared with those of the original dataset. For example, if the coefficient of the original dataset is greater than 95% of the coefficients of the random datasets, then it is significant at the 0.05 level, as it was the same large or larger to five of 100 permutations. Thus, QAP is considered suitable method for this study, due to the dyadic structure (links) of the data and the amount of interactions treated.

5 Explaining the knowledge network by the relative position of the actors

5.1 Model and variables

In this paper, we depicted the collaboration network as an $n \times n$ adjacency matrix, Y , where for every case, y_{ij} is equal to zero, if the actors at i and j positions have no common participation in a project, or y_{ij} is equal to a positive integer that represents the existence and the strength of the tie between these two actors. According to Granovetter (1973), the strength of a tie equals to many times the actors i and j have cooperated between them. The generalized formula that estimates the strength of the undirected ties of the collaboration network is given as follows:

$$y_{ij} = \alpha + \beta'x_{ij} + \varepsilon_{ij} \text{ for all } i < j, \quad (2)$$

where y_{ij} is the value estimated for the relationship between i and j that this model explains. The matrix x_{ij} includes all the explanatory and dummy variables that relate i and j .

The dependent network (*Collaboration*) is the existence and strength of ties in the simplest relationship that implies knowledge transfer, the collaboration network, as it was formed in the end of 2014. It takes the value zero when two actors have not collaborated at all, and a positive integer value if they did, according to the number of projects the two actors have co-participated in. In order to explain the existence and the strength of these relationships, we use three sets of variables: the first one is the *Coordination* and *Funding* networks, representing different types of collaborations that indicate knowledge transfer, the second group is the dummies that

represent the different dimensions of proximity, and the third set is the representation of the relative position of an actor inside the network (in-network proximity).

The coordination network (*Coordination*) is the representation of the relationship between a coordinating actor and the rest of the participants of the project. We take it in consideration as the specific status of certain actors as coordinators of projects, and the interaction of project participants with them may be of importance for stronger collaborations. The funding network (*Funding*) is the depiction of the funding relationship between funding entities and participants of projects. Interactions of participants with these specific actors also may affect the strengthening of collaboration between agents.

In the second set of variables, we use three of the aforementioned dimensions of proximity, namely the geographical (*GEOPROX*), the institutional (*INSTPROX*), and the organizational (*ORGP**ROX*) proximities.² Assuming that two actors are geographically proximate when they are both located inside Trentino, we employ a dummy variable that equals to one in this case and zero otherwise. Institutional proximity relates to the cases when one actor is located inside Trentino and the other in any other region of Italy.³ Consequently, these two actors belong to the same institutional context at the national scale, as they act under the same laws, norms, and culture. The dummy variable we employ to express institutional proximity equals to one if the interaction is national and zero otherwise. The third dummy variable controls for organizational proximity and expresses the case when two actors belong to the same organizational context (they are both universities, research centres, SMEs, large firms, or public agencies).

In the third set of variables employed belong the variables that describe the in-network proximity of actors in different centrality terms. In other words, they express how proximate or distant are two actors according to their relative position inside the knowledge network. We control for the effect of the relative position of the actors in terms of eigenvector centrality. We employ a dummy matrix that includes the cases that two actors are either both central and proximate or distant, while we consider as reference case when they are both peripheral and proximate. Therefore, we employ the following in-network proximity variables: central and proximate actors according to eigenvector centrality (*INNETWORKcentralproximate*) and distant actors according to eigenvector centrality (*INNETWORKdistant*).

² In this paper, we do not control for the effects of cognitive and social dimensions of proximity. There are not sufficient data for the national and regional projects to control for cognitive proximity in the actor level. The omission of these projects would result to the loss of important information on the knowledge creation and transfer network inside the region. On the other hand, this paper does not control for social proximity, as the repeated interactions are treated as an attribute of a relationship of a pair of agents, and not as an attribute of a specific organization.

³ The institutional proximity has been assessed at the national scale. When we split the Italian regions in north and south, assuming that Trentino has more institutional similarities with other Italian regions in the north, the result remained insignificant. Hence, actors in Trentino consider actors located in the rest of the Italian territory as equal, without differentiating between north and south. This probably happens because the institutional setting of Trentino differs considerably from the rest of Italian regions in terms of autonomy.

As the purpose of the paper is to examine the effect that has the similarity or difference in the relative position of two actors on their strong tie connectivity, we test the effect of two similarly or differently positioned actors (H1). For this purpose, we employ the following model.

$$\begin{aligned} \text{Collaboration} = & \text{Coordination} + \text{Funding} + \text{GEOPROX} + \text{INSTPROX} + \text{ORGPX} \\ & + \text{INNETWORKcentralproximate} + \text{INNETWORKdistant} \end{aligned} \quad (3)$$

To test the effects of overlap and substitution between in-network and the other dimensions of proximity on the tie creation, we introduced the interactions between the different proximity dimensions in the above model (1). To express the overlapping effect, we multiplied in-network proximity (INNETWORKcentralproximate) with geographical, institutional and organizational proximities. To express the substitution effect, we multiplied in-network distance (INNETWORKdistant) with the other three dimensions of proximity.

The correlation between the networks and the proximity dimensions, displayed in Table 2, suggests that there is significant interaction between the dependent and independent variables. In some cases, the independent variables are not significantly interacting between them, but still the correlation is not so high for implying autocorrelation between them. This first evidence from the variable correlations is empirically verified in the interpretative analysis discussed in the following session (Table 2).

5.2 The role of in-network proximity in the strategic choices of organizations

Table 3 presents the estimates of Eq. (1), examining the effect of the three groups of factors on the collaboration ties for the period 2000 up to 2014 (Table 3).

The strong coordination and funding ties (other types of knowledge) during the entire period are affecting positively and significantly the overall strong collaboration ties. The effect of the coordination ties appears to be much more intense than the funding ones. This means that the relationship of two actors when one of them is coordinator of a project, affects extensively the strong collaboration between these two actors. Therefore, the management of knowledge by an actor is evaluated more for strong collaborations. The effect is much smaller when the one of the two actors is a funding entity, although still significant.

The second set of variables are three of the traditional dimensions of proximity. The overall effect of the proximity dimensions is positive. However, only the geographical and organizational proximities seem to have a significant effect on the strong collaboration between actors. Therefore, if two actors are located in the same region they create a stronger collaboration, while the fact that two actors are located in the same country does not appear to have an effect on the strong collaboration creation. Yet, two actors that they operate under the same organizational context (they are both SMEs, large firms, universities, research centres, or public bodies), create a strong collaboration between them.

Table 2 Quadratic assignment procedure (QAP) correlations between the variables of the model

Correlation (<i>p</i> value)	Collaboration	Coordination	Funding	Geographical proximity	Institutional proximity	Organizational proximity	In-network central and proximate	In-network distant
Collaboration	1.000 (0.000)							
Coordination	0.476 (0.001)	1.000 (0.000)						
Funding	0.084 (0.001)	0.182 (0.001)	1.000 (0.000)					
Geographical proximity	0.002 (0.059)	0.000 (0.583)	0.007 (0.052)	1.000 (0.000)				
Institutional proximity	0.000 (0.413)	0.001 (0.210)	0.001 (0.203)	0.389 (0.001)	1.000 (0.000)			
Organizational proximity	0.002 (0.047)	0.001 (0.228)	0.001 (0.107)	0.011 (0.001)	0.009 (0.001)	1.000 (0.000)		
In-network central and proximate	0.014 (0.001)	0.000 (0.308)	-0.000 (0.232)	-0.001 (0.120)	-0.000 (0.473)	0.000 (0.333)	1.000 (0.000)	
In-network distant	0.020 (0.001)	0.006 (0.001)	0.004 (0.090)	0.003 (0.185)	0.001 (0.338)	0.010 (0.021)	-0.025 (0.001)	1.000 (0.000)

Table 3 The effect of the different types of in-network proximity on the strong collaborative ties (2000–2014)

	Model without in-network proximity		Model with in-network proximity		Model with overlap and substitution effects	
	Coefficients	Standard Errors	Coefficients	Standard Errors	Coefficients	Standard Errors
<i>Dependent variable: Collaboration ties (2000–2014)</i>						
Coordination	1.330***	0.002	1.330***	0.003	1.330***	0.003
Funding	0.006***	0.003	0.006***	0.002	0.006***	0.002
Geographical Proximity	0.007*	0.005	0.007*	0.004	0.002	0.006
Institutional Proximity	0.001	0.002	0.001	0.002	<0.001	0.003
Organizational Proximity	0.001*	0.000	0.001*	0.000	<0.001	0.001
In-network Central and Proximate			0.161***	0.007	0.179***	0.008
In-network Distant			0.006***	0.001	0.006***	0.001
In-network central and proximate × geographical proximity					<0.001	0.000
In-network distant × geographical proximity					0.007*	0.005
In-network central and proximate × institutional proximity					0.120***	0.035
In-network distant × institutional proximity					0.001	0.002
In-network central and proximate × organizational proximity					0.070***	0.015
In-network distant × organizational proximity					0.001	0.002
R-sq	0.226		0.227		0.001	
Observations	5,728,842		5,728,842		0.227	
					5,728,842	

Significance levels: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The reference in the dummy variable of in-network proximity is the in-network peripheral and proximate. The statistical analysis was performed with UCInet (Borgatti et al. 2002)

The in-network proximity between two central actors is significant for the formation of strong collaborations in the Trentino ICT knowledge network (verifying H1a). This underlines that when two actors are both relatively central in the knowledge network, they tend to repeat the collaboration with each other. Similarly, when two actors are in-network distant, i.e. one is relatively central and the other relatively peripheral, they also tend to repeat the collaboration between them in the ICT field in Trentino (verifying H1b). Without assessing the directionality of this relationship, we can say that two in-network distant actors are creating strong collaborative ties. As the dummy variable of in-network proximity refers to the case that two actors are in-network proximate but both peripheral, in this case the two peripheral actors do not tend to create strong ties between them. Finally, when two actors are central and proximate the effect is higher, in significance and intensity, than when they are in-network distant.

Exploring the overlap and substitution effects between in-network proximity and the other proximity dimensions (i.e. geographical, institutional and organizational), all the hypotheses H2a, H2b and H2c are verified. All the dimensions of proximity interact (either overlap with or substitute) in-network proximity, in order to facilitate actors in the creation of strong ties. However, they interact with in-network proximity in diverse ways and intensities. Geographical proximity presents a weak substitution effect with in-network proximity. This means that when there is in-network distance between two actors that are located in the same region, the geographical proximity compensates for the creation of a strong tie between them. Institutional and organizational proximity dimensions are overlapping with in-network proximity. Therefore, increase and facilitate the creation of strong ties between in-network proximate central actors. Although institutional proximity alone does not affect the creation of strong ties between actors located in Trentino and other Italian actors, it seems to have a significant effect on the strong tie creation between them when these two actors are central and in-network proximate. Similarly, when two actors are of the same organizational type and in-network proximate and central, it is easier to create strong ties between them.

6 Conclusions

Until today, there are several classifications of proximity (Torre and Rallet 2005; Boschma 2005; Broekel and Boschma 2012; Caragliu and Nijkamp 2016) with more frequently used the one of Boschma (2005), which also the present paper follows. Also, several dimensions were added, either differentiating from the most commonly used five dimensions, for example, 'relational proximity' (Coenen et al. 2004), and 'cultural proximity' (Knoben and Oerlemans 2006), or by exploring different non-spatial or network attributes of the actors, like the 'regional network proximity' (Wanzenboeck 2018). However, there was little attention to the relative position of the actors inside the network, and the effect that their position has into their collaboration.

The theoretical contribution of this paper is the introduction of a new type of proximity, taking into consideration the relative position of actors inside the network

in terms of centrality. To this direction, there were several attempts characterized by the absolute differences in centrality (Autant-Bernard et al. 2007; Cassi and Plunket 2015), however, they explore the relative position of the actors partially, as they can express only how much distant are two actors in terms of centrality inside the network. However, the in-network proximity measure, described in this paper and defined in terms of centrality, expresses also the cases when two actors are actually proximate in relative terms inside the network. Two actors may be central and in-network proximate, peripheral and in-network proximate, or in-network distant.

Central and in-network proximate actors create stronger ties than in-network distant actors, which is in line with the preferential attachment (Barabasi and Albert 1999). The centrally positioned actors repeat collaboration with other central actors in the network, as central actors gather more 'reputation', signalling that they will possess the necessary knowledge resources for collaboration. Similarly, also peripheral actors prefer to repeat collaboration with actors relatively positioned more centrally. They make such collaboration choices in order to tap on knowledge resources they do not acquire. Although we cannot control for the directionality of this choice, we speculate that on one hand peripheral actors create strong ties with central actors for strengthening their position in the network and to reach to resources and expertise they may not have. On the other hand, central actors repeat collaborations with more peripheral actors, in order to avoid 'lock-in' situations, getting access to new, external knowledge and skills (Bathelt et al. 2004; Crespo et al. 2013).

Moreover, there are substitution and overlap effects between in-network proximity and the other proximity dimensions (i.e. geographical, institutional, and organizational) that influence the creation of strong ties between actors (Hansen 2015). Between in-network and geographical proximities there was no evidence of overlap effect, but only of substitution effect. Therefore, the strong tie creation between a central and a peripheral actor can be facilitated if these two actors are located in the same region. Conversely, institutional and organizational proximity dimensions indicate only overlap effect with in-network proximity. When two actors are in-network proximate and central create strong collaboration ties (repeated collaborations) when both of them belong to the same institutional or organizational context. This paper contributes conceptually to the literature that distinguishes between overlap and substitution effects, recognizing their simultaneous importance on collaboration formation.

Thus, the findings of this paper convey relevant policy implications, as well. When designing innovation policies, local policymakers have to take into consideration the strategic behaviour of actors in the knowledge transfer process inside the network. During the local policymaking process, they have to take into consideration as well the overlap and substitution effects. Since more central actors are the most preferred for the strong tie creation, non-directed policies are likely to reinforce their dominance in the network, slowing down the emergence of local peripheral actors and new entrants. This strategy may be sub-optimal when local peripheral actors miss opportunities to be chosen for repeated collaboration. The reinforcement of repeated collaboration of central actors may lead to 'lock-in' situations that will not be beneficial for the regional innovation process (Phillips 2011). In fact, innovation policy might be more effective if it is targeting balanced sub-networks of projects, in

order to strengthen the position of the local peripheral actors in the system, including them in the innovation process. This would constitute these local peripheral actors more attractive for future collaborations with new entrants, strengthening the entire knowledge network, and consequently facilitating knowledge transfer.

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