How proximity matters in innovation networks dynamics. Evidence from the High Technology applied to Cultural Goods in Tuscany

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Abstract
The aim of this study is to investigate the dynamics of inter-organisational innovation networks analysing how actors form new network ties according to their proximity. Proximity is intended in a multidimensional level considering geographical, cognitive, organisational, institutional and social proximity.

The analysis investigates the cluster of High Technology applied to Cultural Goods (HTCG) localised in Tuscany, who has developed in last decades several innovations for cultural goods and has participated to several innovation policy supported networks.

The study applies Social Network Analysis to 42 R&D projects developed in over 15 years (1995-2012) and attracting more than 89 M?, in order to analyse the overall network evolution along time.

The paper deals with how actors in HTCG form ties and choose their partner according to different level of proximity by using a Stochastic Actor Oriented Model. This part focuses on micro-level (actor-centred) dynamics and analyse how these influence the formation of the overall network along time.

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1. Introduction

The role of proximity on innovation and networks dynamics has recently received an increasing attention in management studies (Knoben & Oerlemans, 2006; Ritter & Gemunden, 2003), organizational studies (Oerlemans & Meus, 2005), economic geography (Boschma, 2005; Boschma and Frenken, 2010) and regional studies (Huber, 2012; Kirat and Lung, 1999), etc. Nevertheless several theoretical frameworks are used and different forms of proximity are investigated.

The most investigated form of proximity is geographical proximity. Spatial proximity and co-location of economic activities has been traditionally considered as an important factor of competitiveness and innovation starting from Marshall (1890) and the concept of agglomeration economies and industrial district (Becattini et al., 2009) and cluster debate (Porter, 1998). The clustering effect facilitate knowledge spillovers (Breschi and Lissoni, 2001; Audretsch & Feldman, 1996) and promote collaboration among local networks (Asheim & Isaksen, 2002; Sedita & Belussi, 2012). Geographical proximity facilitate also the transmission of information and knowledge among firms and employees (Bell & Zaheer, 2005).

Nevertheless geographical proximity has been recently criticized (Knoben and Oerlemans, 2006) as it does not consider the relevance on global and not-localised knowledge networks. In particular, this strand of research has been particularly prolific in management and organisational studies, where an increasing number of contributions started to investigate the important role of several forms of proximity in knowledge sharing and inter-organizational collaboration (Knoben and Oerlemans, 2006; Ritter & Gemunden, 2003a), innovation success (Lai et al., 2014; Ritter & Gemunden, 2003b) and firms performances (Oerlemans et al., 2005). Some authors even investigate how geographical proximity could impede entrepreneurship and innovation (Ben Lataifa & Rabeau, 2013).

Some studies show also that benefits of geographical proximity in a cluster are not equally distributed to all firms, but this depends on the position of a firm in the local network (Ahuja, 2000; Zaheer & Bell, 2005; Sedita, 2008). Several studies on industrial district and cluster discuss the relationship between knowledge networks and cluster and the firm position (Bell, 2005; Giuliani, 2013), in particular focusing on different roles of formal and informal network (Casanueva et al., 2013; Morrison et al., 2012).

In the strategic network approach, the interest is focused on the importance for a firm to enlarge its boundaries of strategic intervention to the network of relationships (Gulati, 1999; Mc Evily & Zaheer, 1999). This strand of research underlines the relevance of strategic network and network resources (Gulati et al. 2000) or competences (Ritter and Gemunden, 2003b). The ability of a single firm to benefit from network resources originates from the interaction of three components: its endowment of unique resources and knowledge, its network position and the structure of the network itself (Zaheer & Bell, 2005).

Anyway, most research on networks appear mainly static (Ahuja et al., 2009) as they focus more on network structure than at network process, knowledge flows and network dynamics.

Several contributions on different forms of proximity emerge also in Evolutionary Economic Geography (Boschma, 2005, Balland, 2012; Balland et al. 2013; Ter Val,, 2013). This strand of research investigates several forms of proximity underling that the spatial proximity is still a relevant determinant on innovation, development and network dynamics, also in globalised industries.
The aim of this study is to contribute to this debate on the importance of different forms of proximity. The aim is to investigate the role of various forms of proximity in innovation networks dynamics. The article focus on two specific research questions: (i) how do the different forms of proximity matter as determinants of the formation of network ties?; (ii) Is geographical proximity still the main determinant as tie formation, or other forms of proximity are more important?

The article focuses on the cluster of High Technology applied to Cultural Goods (HTCG) localised in Tuscany (Lazzeretti et al., 2011), who has developed in last decades several innovations for cultural goods and has participated to several R&D policy supported project networks (Bellandi & Caloffi, 2010).

It is important to investigate this business as it is a multidisciplinary context, where many disciplines are involved (chemistry, physics, opto-electronics, ITC, etc.) and usually applied to a totally new sector (cultural goods). This could enrich the research agenda on how and which forms of proximity facilitate transversal innovations applied to new sector and industries. This is particular interesting as innovation studies are increasingly focus on transversality and cross-fertilization processes and incremental innovations from one sector to another one (Cooke, 2010; 2012).

For the purpose of this study five forms of proximity are investigated: geographical proximity, social, institutional, cognitive and organisational proximity.

The study applies Social Network Analysis (SNA) to 42 R&D projects developed in over 15 years (1995-2013) and attracting more than 89 M€, in order to investigate the network evolution along time.

The paper uses a stochastic actor-based simulation approach with package SIENA (Snijders, 2001, 2005; Snijders et al., 2010). It focuses on micro-level (actor-centred) dynamics and analyse how these influence the formation of network ties along time.

The analysis point out that the overall network evolved profoundly along the analysed period as it has deeply changed its structure. This macro-level structure has been modified on the basis of actor’s micro dynamics, underlying the role and importance of various dimension of proximity, in particular the geographical and cognitive proximity.
2. Proximity and network dynamics

Scholars on networks evolution and dynamics have stressed the fact that interactive learning and inter-organisational collaborations are easier when actors have similar attributes.

There is a wide strand of research on the role of different dimension of proximity, but most studies are do not try to measure quantitatively different forms of proximity and do not investigate network in an evolutionary perspective.

Among these that have an evolutionary approach, Ballard (2012) investigates proximity and the evolution of collaboration networks in Global Satellite Navigation Systems in the VI FP in the period 2004-2007. He shows that geographical, organisational an institutional proximity favour collaborations, while cognitive and social proximity do not play a significant role. Ballard et al., (2013) study the evolution dynamics of video game industry and the formation of network ties between firms along the life cycle of a creative industry, from 1987-2007. They indicate that the mechanism of formation of ties over time are stable but their weights change over time. Cognitive and geographical proximity are increasing determinant as the industry evolve over time. Morrison et al., (2012) investigate technical and business networks in a toy cluster in Spain confronting different impact of proximity dimensions. Results here underline that cognitive proximity and geographical proximity are the most important issue in promoting a relationship, in particular more in informal networks than in formal relationships.

Ahuja et al. (2009) discuss pre-existing network structure as constrains to the formation of new inter-organizational alliances and Cassi & Plunket (2010) investigate proximity in co-inventor tie formation.

Ter Wal (2013) explore the interplay between geographic distance and triadic closure as two main forces that drive the evolution of collaboration networks, analysing the evolution of inventor networks in German biotechnology. She proves that as the industry changes over time the direct impact of geographic distance on tie formation decreases and that transitivity becomes an increasingly powerful vehicle to generate longer distance collaboration ties as the effect of geographic proximity decreases.

Network researches have pointed out that there is a higher propensity for form ties between actors with similar attributes recalling the concept of homophily (location, age, social status, etc.) (McPherson et al., 2001). Network studies tend to suggest that evolution of the macro structural characteristics of a network is driven by concurrent forces operating at the micro level (Powell & Grodal, 2005; Powell et al., 2005). This idea recalls the sociological network approaches, whether from Granovetter (1973) or Burt (1992) knowledge sharing and acquisition are related to various structural properties of individuals’ positions in knowledge networks (Foss, 2010). The idea of this paper is instead to mainly focus on dyadic relationships and similarity (proximity) between pairs.

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1 Burt (1992) and mainly Granovetter (1973) point out that social networks tend to be characterized by dense sub-network of stable relationships. Knowledge in these sub-network tends to be homogeneous and redundant. New idea and radial innovation are more obtained through new relationship with different actors.
Boschma (2005) stresses the fact that innovation is fostered by various dimensions of proximity. He proposed five dimensions of proximity, in which cognitive, organizational, institutional, social and geographical proximity increase the probability of forming relationships with others. In other words, actors establish collaborations easier with others that are of the same typology, co-located in the same area, belong to the same group, etc..

We follow this contribution notwithstanding that the various forms of proximity are not anonymous in the literature. For instance, Knoben & Oerlemans (2006) present an ISI web literature analysis on several studies on proximity proposing a classification among 7 dimensions: institutional, cultural, social, technological, cognitive, organizational and geographical. Besides, Kirat & Lung (1999) refer to three types of proximity: institutional, organizational and geographical. Nonetheless in this strand of research, most of all contributions focus on the above recalled 5 dimensions (Huber, 2012; Knoben & Oerlemans, 2006).

The literature on externalities usually takes for granted that agglomeration economies derive from three distinct sources; namely, a qualified labour force, specialized suppliers and knowledge spillovers (Rosenthal & Strange, 2004). In this respect, some authors stressed that innovative clusters of small and medium enterprises (SMEs) are characterized by higher levels of inter-firm imitation, sharing of common knowledge, and mutual learning among organizations (Tallman et al. 2004; Sedita, 2008). Geographical proximity facilitates also the transmission of knowledge among firms and employees (Bell & Zaheer, 2005)

**Hypothesis 1**: actors are more likely to form ties with actors co-located in the same cluster or geographically close to each other.

The other four dimensions appear to be disconnected from the physical proximity, as they express a relational proximity that is related to the interaction between actors (Amin & Cohendet, 2003).

The concept of cognitive proximity has been developed by Nooteboom (1999). Cognitive proximity is commonly defined as the similarities in the way actors perceive, interpret, understand and evaluate the world (Knoben & Oerlemans, 2006).

Cognitive Proximity is an element particular important for promoting innovation, starting from the concept of absorptive capacity (Cohen & Levinthal, 1990) and of knowledge bases (Noteboom, 1999) and the school of proximité (Torre & Rallet, 2005). Firms having a similar knowledge base exchange and acquire external knowledge more easily and efficiently. This could be done or investing in R&D internally or acquiring external employees in order to develop a shift in the level of internal absorptive capacity. This issue bring attention to a cluster level absorptive capacity and to a different network level of absorptive capacity (Giuliani, 2013). Also the related-variety approach (Frenken et al., 2007), which has received a growing attention in literature, is applied to try and identify the key factors of economic development at both regional and national levels, by pointing up the need for a local system to have a certain degree of cognitive proximity so as to promote innovation and economic development in the area.

**Hypothesis 2**: actors are more likely to form ties with actors that have a similar level of absorptive capacity or with whom they share a same language or knowledge base.
Organisational proximity indicates that firms of the same corporate group are willing to share knowledge easier and have a better facility to innovate (Boschma, 2005; Balland, 2012). Cohen et al. (1996) define organisation proximity as routine as an executable capability for repeated performance in some context that has been learned by an organization in response to selective pressures. Previous experience of collaboration indicate the development of organisational routine and then a better capacity to work together and participate to R&D projects. This is particular true for temporary project organisations in policy supported project network (Sedita, 2008).

**Hypothesis 3**: actors are more likely to form ties with same corporate group and with actor that share the same organisational routines. Previous collaboration also indicate a development of organisational routine and consequently a higher propensity to collaborate in future.

Institutional proximity is defined by the similarity of informal constraints and formal ruled shared by actors. Usually this aspects is related to the belonging to the same institutional form as also Triple Helix model (Leydesdorff & Etzkowitz, 2000). It measures whether two firms are exposed to the same institutional context (Balland et al., 2013). In other words, sharing formal or informal rules and codes increases the likelihood of actors to start a partnership.

**Hypothesis 4**: actors are more likely to form ties with similar typology of actor, but in order to participate to policy supported project networks actor could also try to establish relationships with new actors in order to increase the heterogeneity of the knowledge in the network.

Social (relational) proximity refers to the fact that economic relationships may reflect social ties (Granovetter, 1985). Social proximity refers to the degree of common relationship to diffuse informal knowledge i.e. the same behaviours in relationships dynamics (Balland, 2012).

This element recalls the sociological approach to study innovation networks (Powell & Grodal, 2005; Powell et al., 2005). Here the innovative performance of firms is related to a higher propensity to form ties and relationships with similar from a (social) relational perspective. Relationships in this context develops more among firms that have similar behaviours and network partners as the rich get richer in Powell et al., (2005) or the so-called phenomenon of preferential attachment (MCPherson et al., 2001). This proximity is based on the way specific agents more or less deliberately positioned in (production, R&D, etc.) relationships with other agents, and the way the agents shape and maintain relations (Lagendijk & Lorentzen, 2007).

**Hypothesis 5**: actor are more likely to form ties with firms that have the same social network behaviour. More central actor in the network will probably form ties with other central actor, thus closing more and more along time the core network.

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2 A preferential attachment is a process where some quantity, some form of wealth or credit, is distributed among a number of nodes in a network according to how much they already have, so that those who are already wealthy receive more.
3. Research design

3.1. Research design and methodological approach

The present study represents the last stage of a long-term research project focusing on the cluster of high technology applied to cultural goods in Florence and Tuscany (Lazzeretti et al., 2011). The analysis investigates the co-participation in innovation policy-supported project network developed in the region in the field of the safeguard and enhancement of cultural heritage.

The R&D projects were selected through a survey submitted by e-mail to the main regional research organizations specialized in this field. The Institute of Applied Physics of the National Council for Research (IFAC-CNR) was the first interviewed actor, identified as the key player in the development of laser technologies for restoration (Lazzeretti et al., 2011). The other actors are the organizations that have shared the proposal presented by IFAC-CNR for a regional Technology District for Cultural Goods, that also coordinated several projects developed over the last 15 years in the field of cultural goods in Tuscany.

We have interviewed all the (public) research centres, universities and operating in the Region of Tuscany involved in HTCG. The interviewed group included 15 actors, including 6 research centres affiliated to national institutes of research and 9 university departments and faculties.

To the best of our knowledge, we have collected all the R&D project on HTCG business. As a result, 42 projects were collected in the database. They were funded through regional, national and international calls covering a time-span of over 15 years (1995-2012) involving SME and large firms, Research centres and University.

Face-to-face interviews with the leading actors were conducted in first semester of 2011 and then in 2012, a first online questionnaire was administered at the end of 2011 and a final control was done in 2012 in order to collect information on all of the projects implemented at a regional, national and international level with the participation of firms and institutions.

In order to analyse network dynamics between the actors, the database was organized in order to apply SNA (Wasserman e Faust, 1994) with the objective of highlighting the inter-organizational relationships activated by the co-participation into projects. The two-mode network has then been transformed to a one-mode network. The link between two actors indicates the co-participation to a same project.

For each actor, in addition to the number of project to which it has participated, other attributes have been investigated for elaborating descriptive statistics: received financial contributions; location; typology; competences, etc.

The second part of the paper investigate the formation of network ties according to different level proximity by using a stochastic actor-based simulation approach with package SIENA (Snijders, 2001; 2005; Snijders et al., 2010).

This part focuses on micro-level (actor-centred) dynamics and analyse how these influence the formation of the overall network along time (2005-2010). Innovation literature on networks dynamics are increasingly focus on stochastic agent-based simulation techniques (Giuliani, 2013; Ter Wal, 2011; 2013; Broekel et al. 2014), in order to investigate network dynamics and change during time.
3.2. High technology applied to cultural goods in Tuscany

High technology applied to cultural goods is a newly emerging business for firms in various industries, such as ICT, geology, chemistry, biology, engineering and physco-optoelectronics (Casprini et al. 2013).

This is particular true for Florence and Tuscany where a technological cluster has been formed during time, specialised in restoration and enhancement of rich local cultural heritage and recognised at international level (Lazzeretti et al., 2011).

The cluster has started to develop in early years of 2000, thank to policy supporting inter-organisational network in high-technology applied to cultural goods. The cluster develop rapidly and in around 10 years arrived to more than 400 associated actors: firm, research centres and universities (Salimbeni, 2012). In 2011, Tuscany Region recognised the relevance of this sector funding the Technological District in Cultural Goods (TDCG) in order to support the local R&D activities and improve the local governance.

Recent research has been also devoted to study innovation in HTCG. Casprini et al. (2013) analyse business modules in HTCG analysing 30 firms in Tuscany. Lazzeretti and Capone (2015) pointed out the HCTG is a particular interesting sector, that develops transversal innovations related to several scientific domains.

A first example is the development of Nd:YAG laser for the restoration of cultural heritage, built in a policy-supported R&D project among a local large multinational firm with expertise in laser for biomed, the National Research Centre (CNR) with high skills in Optoelectronics and Physics and local cultural organizations (Salimbeni et al., 2002). A second important innovation is the development of chemical nanotechnologies and gels for the conservation and restoration of cultural heritage, development at the University of Florence by the network of researchers from the Department of Chemistry (Baglioni et al., 2009).

A last important innovation that developed a relevant impact is the 3D visualization and rendering software and digitization of cultural heritage and in particular the digitalization of the work of arts at the Uffizi (Uffizi Touch™) that has significant impact at firms level (Cappellini et al., 2003; Centrica, 2013).

Moreover this business has received in last year an increasing interest also from Italian authorities in designing industrial policy and technological districts for cultural goods to improve the competitiveness of local firms (Di Pietro et al., 2014). HTCG is particular relevant for innovation studies as is a high technology and complex sector, based on transversality and cross-fertilization processes in policy-supported R&D projects (Bellandi and Caloffi, 2010).

3.3. The selected R&D policy supported projects networks

The selected 42 projects cover a time frame of fifteen years (1995–2012) and registered a total investment of 89 M€. The R&D projects deal with restoration and enhancement of cultural heritage in regional, national and international Calls.

The technological advancement of projects is rather broad and encompasses technologies for the preservation, diagnostics, restoration, documentation, fruition of cultural goods. It is therefore representative of a wide range of initiatives which converge toward the application of high technology for cultural goods, in its broadest sense.

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The R&D projects are of different size and importance. The largest percentage regards small projects under 0.5M€ and large projects over 2M€. Small projects have an average of 4 partners, while large projects arrive up to 15 partners.

The majority of actor is Italian, representing around 55% of the total. However, the network has an international dimension, as the European actors account for around the 45%. Within Italy, Tuscany and specifically Florence, are the most relevant locations with more than 23% of actors located in Florence and 18% in Tuscany. The Pisa area also plays a particularly important role with 35 players and approximately 9% of the total.

The analysis of the typology of actors confirms the high participation of research centres, universities and firms. Altogether, these three groups account for over 75% of all actors, with an important role of the research centres (about 31% of total), followed by firms (17.6%), which includes both SMEs and large companies. Regarding actors' competences, actors have been classified on the basis of their contribution in the project, instead of their generic sector of activity. ICT for cultural heritage is the area that records the highest participation, representing the 22.3% of the total.

It is followed by the area of Conservation with about 13.5%. Optoelectronics settles down to 10% of participants. ICT together with 3D Visualisation accounts for more than 30% of the total. Other significant areas of expertise are Physics, with 7.3%, Restoration with 7.4% and Chemistry with 6%.
4. The evolution of innovation networks in HTCG

This section deals with the analysis of the evolution of network in HTCG. Figure 1 presents the evolution of the network from 1995 to 2012, showing the number of involved actors, the density of the network and entry and exit dynamics. The network developed in the early 2000s, recorded a significant growth in the last decade reaching 450 actors with about 50 entries per year\(^4\). This confirm the importance of this business, which has attracted more and more companies, research centres and universities.

Which were the determinants of the change of the network? and how actors select their partner and form partnerships in order to participate to R&D projects? This section aims to investigate the evolutionary dynamics of the network according to a micro approach In this context, the meso structure of the networks the results of the choices (at micro level) of individual actors (Bell, 2005; Foss, 2010).

**Figure 1: Actors’ entry, exit and density in HTCG.**

![Figure 1: Actors’ entry, exit and density in HTCG.](image)

Source: authors elaborations.

Figures 2-4 present the different configuration of the network since 2000 the first year of development, 2005, a year of intermediate growth and 2010, as the year of full development and affirmation of the network. The network passes from a first stage of birth to a first development stage and it is at the moment still growing. The network in 2000 shows a weak network structure focused on institutional and research centres, which are major players. The network is cohesive, but focused on few actors.

\(^4\) Exits are computed as an actor exit from the network and not participated anymore to any project with other actors.
In 2005, a substantial change starts to emerge. The network becomes steadily more structured, the number of actors grows exponentially. Among the actors, also economic actors start to appear such as small and large firms. The overall network however is composed of sub-network according to different disciplines. There are two sub-network for Physics applied to cultural heritage and Earth Science and a sub-network on Digitalisation and 3D Visualisation, more based on European partners, and finally a large sub-network centred on Optoelectronics and Laser competences with actors mainly located in Tuscany. The smaller sub-networks are still composed by institutional actors and research organizations, while the sub-network of larger size involved also many local small and medium enterprises. The network at 2010 is fully connected around the previously identified sub-networks, all players in the Triple Helix emerge and the connection of the network is very thick. This configuration shows a phase of full development of the global network that achieves a high level of complexity.

Figure 2: The evolution of the networks on HTCG, 2000

Source: authors elaborations.

Figure 3: The evolution of the networks on HTCG, 2005

Source: authors elaborations.
Table 1 presents the descriptive indexes of the network in the three periods. The **avg. degree** increased in the period, pointing out a network that gradually became more and more complex. The **density** of the network decrease from 0.6 to 0.1 underlining a network that gradually become less cohesive. The **avg. distance** gradually increases in the period with the growth of the network and so the **breadth**. The number of actors increase from 26 in 2000 to 357 in 2010. Which are the processes that led the network to this particular configurations? The next section will try to respond to this question through a statistical analysis with SAOM (Snijders, 2001; 2005; Snijders et al., 2007).

Even the percentage composition of the actors changes during the period (Tab. 1). In 2000 Universities and Institutions are the most numerous (27% and 23%) with few companies (16%). In 2005, Universities and Research Centres became the majority, while firms rise up to 18%. In 2010, firms reach 22%, while institutions decrease to 15%. The network originated from an institutional and public configuration turns into a network of firms, universities and research centres.
Table 1: The evolution of the network. SNA index and composition.

<table>
<thead>
<tr>
<th>Network indexes</th>
<th>2000</th>
<th>2005</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Projects</td>
<td>7</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td>Avg Degree</td>
<td>7.538</td>
<td>29.554</td>
<td>24.569</td>
</tr>
<tr>
<td>Density</td>
<td>0.628</td>
<td>0.214</td>
<td>0.097</td>
</tr>
<tr>
<td>Connectedness</td>
<td>1</td>
<td>0.704</td>
<td>0.939</td>
</tr>
<tr>
<td>Fragmentation</td>
<td>0</td>
<td>0.296</td>
<td>0.061</td>
</tr>
<tr>
<td>Avg Distance</td>
<td>1.372</td>
<td>2.025</td>
<td>2.519</td>
</tr>
<tr>
<td>No. actors</td>
<td>26</td>
<td>172</td>
<td>357</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Actors composition of the network</th>
<th>2000 %</th>
<th>2005 %</th>
<th>2010 %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firms (%)</td>
<td>16</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>Institutions (%)</td>
<td>23</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>Research Organisations (%)</td>
<td>23</td>
<td>29</td>
<td>28</td>
</tr>
<tr>
<td>University (%)</td>
<td>27</td>
<td>37</td>
<td>31</td>
</tr>
</tbody>
</table>

Source: authors elaborations.

It is then interesting to investigate the evolution of the overall network from its period of birth to its full development (2005-2010). The choice of the period of analysis is motivated by several aspects. The overall network in 2010 is composed by actors that have participated to the constitution of the Technological District in Cultural Goods (TDCG) in Tuscany (Salimbeni, 2011) and therefore they have been acknowledge by institutions as the main actors in the HTCG so far. Moreover, the period 2005-2010, it is considered a growth period of the network to its full development and this is relevant in order to investigate the actors’ relationships dynamics.
5. The analysis of the network dynamics

5.1. The model

This section aims to investigate the dynamic of network evolution using a micro-actor approach and stochastic actor oriented models (Snijders, 2005, 2006). The module SIENA of R (Simulation Investigation for Empirical Network Analysis) carries out the statistical estimation of models for the evolution of social networks according to the dynamic actor-oriented model of Snijders (2001, 2005).

Stochastic actor-oriented models are used to model longitudinal network data. The dependent variable is the evolving relation network, represented by repeated measurements of a directed graph. The network evolution is modelled as the consequence of actors initiating new relations or withdrawing existing relations such that a more rewarding configuration for the actor in the network emerges, to which is added a random influence. This goal is modelled in a so-called objective function the actors try to maximize. The models are continuous-time Markov chain models that are implemented as simulation models.

Siena is recognised as a very promising tool to study the dynamic of networks (Giuliani, 2013; Ter Wal, 2013; Balland et al., 2012). As the model estimates and test parameters from empirical data, it considers networks changes as an evolutionary process. It considers micro dynamics to form the overall network evolution and considers change as an iterative process, between two or more observed moments.

SIENA uses an iterative Markov chain Monte Carlo algorithm to estimate parameters from observed data based on the methods of moments. The first observed network is used as the starting point for the simulations. The stochastic approximation algorithm simulates the evolution of the network and estimates the parameters that minimize the deviation between the observed and simulated network.

The estimation is modelled though two functions (Snijders et al., 2010). The first is called ‘rate function’ and it is a function of distribution along time and it specifies the frequency in which actors change a relation within the network (form or remove a tie). It can be equally to all the actors or depend to single actor’s attribute or its position on the network.

The action taken by each actors is stochastic determined by the second function called ‘objective function’. This function is divided in three parts: an ‘evaluation function’ that models the satisfaction of actors in the different possible configuration of the network, an ‘endowment function’ that is linked to the satisfaction deriving from different action that has taken to this specific configuration and a casual component referred to residual effect.

In a simple specification, the model can be estimated only with the evaluation function, considering constant the rate and endowment function.

In the simple specification, the probabilities of an actor to form or withdraw a tie depend on the objective function, which expresses how likely it is that an actor will change its network, and is a weighted sum of a set of effects:

\[ f_i(\beta, x) = \sum_{k=1}^{L} \beta_k s_{ik}(x) \]
where \( f(\beta, x) \) is the value of the objective function for actor and \( \beta_k \) are the statistical parameters indicating the strength of the effect \( s_{ki}(x) \). The \( s_{ki}(x) \) are the effects (selected from among a range of structural, individual covariate and dyadic covariate effects). If \( \beta_k \) equals 0, the corresponding effect plays no role in the network dynamics, if \( \beta_k \) is positive then there will be a higher probability of moving in a direction where the corresponding effect will be higher. If \( \beta_k \) is negative the contrary applies.

Estimates of the parameters in the objective function are approximately normally distributed, which means that the parameters can be tested by referring the t-ratio to a standard normal distribution (Snijders et al., 2007).

The probability that an actor \( i \) makes a change and chooses between some set \( C \) of possible new states of the network is given by:

\[
p_{ij}(x) = \frac{\exp \left( f_i(x(i \sim \rightarrow j)) \right)}{\sum_{h=1, h \neq i}^{q} \exp \left( f_i(x(i \sim \rightarrow h)) \right)} \quad (j \neq i)
\]

Where \( p_i(x) \) is the probability of changing anything. Higher values of the objective function indicate the preferred direction of changes.

This formula is used in multinomial logistic regressions and means that the probability of an actor making a change is proportional to the exponential transformation of the objective function of the new network resulting from this change (Snijders et al., 2010). Next paragraph will describes the \( s_{ki}(x) \) effect applied in our study.

As said, SAOM can take account of three classes of effects: (i) structural effects, derived from sociological theories and depend on the structure of the network (degree effect, reciprocity, network closure, etc.); (ii) actors individual covariate effects, which consider actors’ characteristics (size, revenue, industry, R&D expenses, etc.); (iii) dyadic covariate effects, based on the existence of some kind of proximity or distance between pairs of actors in the network. This study focuses on this latter element.
5.2. Operationalization of the variables

The various meaning of proximity as a driver of inter-firm cooperation concept have been turned into variables (Tab. 2). Geographical proximity is determined according to a co-location of actors. This effect has been divided also into four classes as located in the municipality of Florence, in the Region of Tuscany, Italy or Europe. Cognitive proximity occurs when organisation share the same kind of knowledge base. This permits to exchange knowledge and communicate faster and more easily. Each actor has been classified on the basis on its role in the project and respect these classes (Environmental, Chemistry, Conservation, Diagnostic, Physics, ICT, Optoelectronics, Restoration, Visual. 3d). These are in other words the scientific domains of the actors related to the HTCG.

Institutional proximity is usually defined when organisation have the same institutional form according to the Triple-Helix model (Etzkowitz & Leydensdorf, 2000) Therefore we classified actors on the basis of following classes: Research centres, Cultural and public institutions, small and large firms and Universities.

Social proximity is usually measured as triangle or dyadic closure in directed network. As cliques could not be considered as a coherent measure in bipartite data. Balland (2012) underlines that accounting transitive triplets to measure transitivity are inadequate to affiliations networks constructed from bipartite data (Robins and Alexander, 2004) and lead to an artificially high transitivity parameter (by construction of the data, each project is a clique (triangle), where organizations are fully connected). Social proximity is then measured with ‘Number of actor pairs at distance 2’ that is a measure of transitivity already used in other researches (Balland, 2012).

Organisational proximity is usually measured analysing formal inter-organisational relationships considering for instance firms of the same group (Balland et al., 2013). In our case this is not relevant as there are not groups involved. We opt to measure it using as a proxy temporary project organisation. This is particular true in temporary project organisation formed to participate into policy supported network. Organisational proximity is therefore measured by the year of collaborations of a pair, that means that two actors that work together for some years developed some organisational routines (Cohen et al., 1996) that help them work together.

As control variables, actor’s attributes are also considered: Experience on HTCG project (no. of years) and Size as the no. of involved project and eventually the role as Project leader.
Table 2: Operationalization of the variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Operationalization</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximity</strong></td>
<td></td>
</tr>
<tr>
<td>H1. Geographical proximity</td>
<td>Co-location in municipality (same region / country)</td>
</tr>
<tr>
<td>H2. Institutional proximity</td>
<td>Same typology (firms, cultural organisation, research centres / universities)</td>
</tr>
<tr>
<td>H3. Cognitive proximity</td>
<td>Same scientific domains</td>
</tr>
<tr>
<td>H4. Organisational Proximity</td>
<td>Experience ego per experience alter</td>
</tr>
<tr>
<td>H5. Social (network) proximity</td>
<td>Number of actor pairs at distance 2</td>
</tr>
<tr>
<td><strong>Status effect</strong></td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>Degree</td>
</tr>
<tr>
<td>Preferential attachment</td>
<td>Degree of alter</td>
</tr>
<tr>
<td><strong>Attributes (actor)</strong></td>
<td></td>
</tr>
<tr>
<td>Funds</td>
<td>Total collected funds</td>
</tr>
<tr>
<td>Experience</td>
<td>Numbers of years since entry in HTCG network</td>
</tr>
<tr>
<td>Number of funded projects</td>
<td>Number of funded projects</td>
</tr>
<tr>
<td>Leadership</td>
<td>Project leader</td>
</tr>
</tbody>
</table>

Source: our elaboration.

5.3. Estimation results

Results of parameters estimation are presented in Table 3 elaborated with SIENA. All estimation are based on 1000 simulations runs and 4 phases. Conditional Method of Moments is used. The convergence of the models is good in all cases (t-ratios were all inferior to 0.10 for all coefficients) and no problems of multicollinearity were encountered.

The rate parameter shows the actor’s probability of formation of new ties during the period as a measure of network change. We found a significant and negative impact of the density effect in all the models (as normally in these type of study). Model 1 estimates actors’ attribute, while Model 2 include also proximity variable, when a parameter is positive and significant indicates that is a determinant of tie formation.

5 The parameter estimates of SAOM can be interpreted as non-standardized coefficients obtained from logistic regression analysis (Steglich et al., 2010). Therefore, the parameter reported in Table 3 are log-odds ratio, corresponding to how the log-odds of tie formation change with one unit change in the corresponding independent variable. To obtain odds ratios, one can simply compute the exponentiated form of the coefficients of each predictor.

6 Estimation have been controlled also with an ERGM procedure and estimation is confirmed to be robust. ERGM results confirm the sign of the estimation.
The value of the rate parameter is positive and significant. It indicates that on average every actor established four new relationships, almost one per year. The parameter of the degree is negative and shows a similar value to other studies on the dynamics of the network. The parameter of the *preferential attachment* is positive, but not significant. An effect that recall the idea of "friends of friends become friends" or "richer get richer" (Powell et al., 2006).

We now analyse the parameters to the various dimension of proximity. Geographical proximity as expected is an important factor, as firms tend to develop relationships with others actors of the same cluster. Cognitive proximity is positive and shows that the analysed actors are more likely to create new relationships with other subjects of the same scientific domain, on the contrary of what could be expected in the field HTCG rich of transversal innovations and from cross-fertilization dynamics. These values are the highest\(^7\) and they are the most influencing into the creation of new ties.

Institutional proximity is rather negative and probably since the Calls usually require an heterogeneous partnership, relationships are more often created with partners of different typology.

Organisational proximity is positive and significant even if it is very close to zero, thus indicating that the experience developed between two actors is a small factor for the creation of new tie during the period.

Social proximity is significant but negative. This indicates that there is no *transitivity* among actors and that triangles (cliques) in the initial period do not tend to *(transitivity) closure*\(^8\) at the end of the period. This parameter does not show a trend of social proximity in the development of the network. In other words, actors are less likely to develop relationships with other actors, that have a similar behaviour at the relational level in the network. Here there is a trend towards more competition and a tendency among actors to avoid central actors in the network. This is also confirmed by control variables, such as *Funds* and *Number of funded projects*.

The parameter of *Funds* is significant and negative. The similarity in the funds collected does not influence the creation of new relationships, rather actors creates ties with firms who have a different pattern. Besides, the parameter of *Leadership* is positive and evidence that Leaders have a higher probability to create new tie. *Number of projects* is rather negative and significant. It evidences that the choice of a new partner is more done among new members instead of those who have already received substantial funding in the past, less than in the leadership case. Figure 5 graphically represents the estimated parameters of the empirical analysis.

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\(^7\) We remind that coefficient are not standardised and they could not be evaluated in comparison.

\(^8\) The concept of *transitivity closure* means that each node is reachable from a specific configuration. For instance, in a triangle if \(a\) is connected with \(b\) and \(b\) is connected with \(c\), a closure of the triangle means that in the future \(a\) will be connected to \(c\). It this way the triangle will be `closed`.
<table>
<thead>
<tr>
<th>Variables</th>
<th>Model 1</th>
<th>Model 2</th>
<th>T-ratio</th>
<th>T-ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate Parameter</td>
<td>4.4566***</td>
<td>4.6739***</td>
<td>25.47</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0098)</td>
<td>(0.1835)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Degree (density)</td>
<td>-0.3041***</td>
<td>-0.609</td>
<td>1.41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0970)</td>
<td>(0.4332)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preferential attachment</td>
<td>2.6685</td>
<td>1.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(degree of alter)</td>
<td>(1.9125)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geographical proximity</td>
<td>1.4646***</td>
<td>4.17</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.3512)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cognitive proximity</td>
<td>0.9663***</td>
<td>3.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.3009)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Institutional Proximity</td>
<td>-0.0339</td>
<td>0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.2612)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organisational proximity</td>
<td>0.0220***</td>
<td>3.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0069)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social proximity</td>
<td>-0.4531***</td>
<td>4.67</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.0971)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Funds similarity</td>
<td>-1.2023***</td>
<td>4.0264</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.2986)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leadership similarity</td>
<td>3.3067***</td>
<td>8.2957</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.3986)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience</td>
<td>3.5518***</td>
<td>19.1575</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.1854)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. project</td>
<td>-6.6663***</td>
<td>21.7781</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.3061)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iterations</td>
<td>1220</td>
<td>1606</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors elaborations. Standard error in brackets. ***: significance at 0.01 level.

---

Estimates of the parameters in the objective function are approximately normally distributed, which means that the parameters can be tested by referring the t-ratio (parameter estimate divided by the standard error) to a standard normal distribution (Snijders et al., 2010). Snijders (1996) propose to approximate them to a standard normal distribution, and consider absolute values greater than 2 as significant at the 5% level, and absolute values greater than 2.5 as significant at the 1% level.
Figure 5: Estimates parameters with SIENA. Graphical representations.

Source: Authors elaborations. *: Not significance. Legend: Red: (0) null influence on ties formation.
6. Conclusions

The study aimed to measure different forms of proximity as determinants of the formation of network ties in the HTCG sector and investigate if geographical proximity was still the main determinant as tie formation, or other forms of proximity.

Proximity was intended in a multidimensional level considering geographical, cognitive, organisational, institutional and social proximity. Starting from 42 policy supported project networks, Stochastic Actor Oriented Modelling was applied to the overall network evolution from 2005 till 2010, from its birth to a full development. We focused on micro-level (actor-centred) dynamics and we analysed how these factors influence the formation of the overall network along time.

The results are satisfactory and emphasize the importance of different forms of proximity to the formation of innovation network ties.

Geographical proximity as expected is an important factor. Firms tend to develop relationships with others actors of the same cluster and this confirm the relevance of co-location of actors in the same geographical context. This dimension facilitates not only the exchange of explicit knowledge, but also the acquisition of tacit knowledge, otherwise not acquirable from far away.

But this is not the only one determinant. Cognitive proximity is also relevant in our study. In HTCG actors are more likely to create new relationships with other actors with the same knowledge base. This could be on the contrary of what could be expected in the HTCG business, where transversal innovations and from cross-fertilization dynamics are very important. This can be explained by the fact that the analysed R&D projects are themselves projects of cross-fertilization, as they apply knowledge developed in high-technology in the business of cultural goods. This complexity leads to create network ties between actors within the same scientific community for developing innovation in a new business.

Institutional and Organisational proximity are not really relevant in our study, but this could be due as the policy supported networks usually require heterogeneous networks. In fact, relationships are more often created with partners of different typology. This is also true in HTCG, where the works of art (needed to test the new technology) are usually in the public hand. Therefore private actors have to involve public organisations into a (R&D) projects or initiatives. In addition, firms usually do not have sufficient knowledge to develop a particular technology, that is why they usually collaborate in University-Industry relationships.

The last form of proximity is Social proximity that is significant in the study, but negative. Actors are less likely to develop new ties with other actors that have a similar behaviour at the relational level in the network.

This can be explained by the fact that in a network in a phase of full development, actors, in particular firms, acquire strategic structural positions after long time and rarely form new partnerships with competitors. In fact, in the study the formation of new ties involve mainly new partners and new entrants in the business. In light of this aspect, the core network appears restricted and closed and also in HTCG the typical dynamics of core-periphery emerge.

In conclusion, this analysis contributes to add new knowledge to the study of various forms of proximity in the formation of network ties in innovation network and measures different determinants that influence the creation of inter-organizational network ties, between firms, Research Centres and Universities.

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10 We remind that the cognitive proximity was measured on the basis of belonging to same scientific domain.
The definition of different forms of proximity should be deepen in the future as there is still no clarity and unanimity on the various dimension of proximity in the existing multidisciplinary literature. Also the operationalization of the variables should necessarily be improved in the future with other information and database in order to better grasp different aspect in the formation on new network ties.

However, this study is part of an interesting and growing strand of research on innovation network dynamics in which the evolutionary approach with robust quantitative methods allow to propose relevant results.
References


