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Knowledge Networks in Emerging ICT Regional Innovation Systems:

An Explorative Study of the Knowledge Network of Trentino ICT Innovation System

A dissertation submitted to the doctoral school of local development and global dynamics in partial fulfillment of the requirements for the doctoral degree (Ph.D.) in Local Development and Global Dynamics

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“As you set out for Ithaka
hope the voyage is a long one,
full of adventure, full of discovery.
Laistrygonians and Cyclops,
angry Poseidon—don’t be afraid of them:
you’ll never find things like that on your way
as long as you keep your thoughts raised high,
as long as a rare excitement
stirs your spirit and your body.”
C.P. Cavafy (1863 – 1933)

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Abstract

Although the last thirty years Regional Innovation Systems (RIS) received great attention by policy makers, only during the last decade social networks were applied in the fields of innovation and regional economics. The majority of the existing empirical studies on networks adopt a static point of view, representing a regional knowledge network at a certain point in time, while there are few recent attempts exploring the evolution of knowledge networks and the dynamics that drive it.

The present work aims at covering some of the gaps in the literature, using the dataset on collaborative projects from the ICT activity in Trentino. It introduces an original multidimensional framework to analyze the knowledge flows inside, from within and towards the regional network. It also identifies the key actors inside the region and describes their role in knowledge creation and diffusion. Concerning the spatial and temporal evolution of the knowledge networks, this thesis investigates the preferences of the economic actors operating inside regional networks, in terms of shared characteristics, while it explores the dynamics developed through time by the behavior of economic agents during high and low certainty periods, contributing to the inertia and the resilience of the regional knowledge network.

The present research is the first that introduces Social Network Analysis (SNA) using data on knowledge transfer from Trentino, considering the entire universe of actors involved in the regional ICT knowledge network for the last fifteen years, and allocating it to an original multidimensional framework, in order to reveal the value of the knowledge network per se, and the impact of the regional policies on the network and not on the output of the innovation process.

On the spatial evolution of networks, it explores in depth the preferences of the actors of a regional knowledge network, in order to make it more solid through strong collaborations. It proves that the effect of every kind of proximity or distance is different, while it introduces the measure of relational proximity, exploring the effect of the position of an actor inside the knowledge network in relation with the rest of the actors. However, the major finding of this thesis is the introduction of the temporal aspect in the evolution of the regional knowledge network, and the exploration of the agent behavior during periods of uncertainty. The introduction in the network evolution of an external negative event, like economic crisis, allows the deduction of useful conclusions on how the actors behave in terms of trust and collaboration creation.

Keywords: knowledge networks, network dynamics, knowledge flows, regional innovation systems

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CHAPTER 1

INTRODUCTION

During the last thirty years the attention of governments and supra-national institutions on the systems of innovation that foster the economic growth globally, nationally, and regionally, largely increased. Particularly, Regional Innovation Systems (RIS) received great attention by policy makers, as the characteristics, the potential, and the dynamics of every region differ significantly in terms of innovation (Cooke, 2001).

Innovation is considered a locally embedded process, and the benefits from this localization, including the knowledge creation and transfer, contribute to the competitive advantage of the region (Asheim & Gertler, 2004). So, knowledge creation and transfer through networks in a region constitutes a significant element of the RIS. This process produces knowledge spillovers and flows inside, from within and towards the knowledge network of the RIS (Cooke, 2001; Fischer, 2001; Bathelt et al, 2004).

A key chapter in this literature on knowledge networks and their flows is how the agents develop trust with other agents in order to create and transfer knowledge. The trust between agents can be developed in two ways: either when the agents trust other agents with which they successfully cooperated in the past (Granovetter, 1983; Krackhardt & Stern, 1998), or when they trust other agents with which they share similar characteristics (Boschma, 2005).

For analyzing empirically the knowledge network, the literature used SNA to describe and analyze relationships between individuals, firms, and institutions that indicate knowledge flows and spillovers. Thus, SNA constitutes a useful tool, contributing further to the analysis of the knowledge network and the RIS in spatial and temporal aspects. While the use of SNA to describe and analyze knowledge flows over space is widely adopted (Giuliani & Bell, 2005; Morrison, 2008), it is less clear how to study the evolution of these connections over time (ter Wall & Boschma, 2009; 2011). There are some attempts in the literature to investigate the dynamics of the knowledge networks (Cantner & Graf, 2006; Broekel & Boschma, 2012; ter Wal, 2013); however, they are still far from being explored. There are gaps in the literature in studying in a more profound way the drivers of the knowledge network evolution.

1.1 The Problem

In a world characterized by the decreasing importance of physical distance interactions are increasing more and more. Therefore, knowledge is diffusing faster than in the past through new channels. This process had a huge impact on the cooperation activities of economic agents. Thus, the focus of public policies, in regional, national, and supra-national levels has turned on regional systems of innovation and their connectivity. Despite of this, the economic literature devoted to the study of social networks of knowledge inside the RIS and economic interactions of agents in some aspects still needs to be explored.

Until now the majority of the literature in knowledge networks considers the network from a static point of view (Giulianni & Bell, 2005; Morrison, 2008). However, recently the research focus has turned to the dynamics leading the knowledge network evolution inside the RIS. Although there is some empirical research on this field (Cantner & Graf, 2006; Broekel & Boschma, 2012; ter Wal, 2013), there is still more to examine in both spatial and time dimensions.

The present thesis aims to cover some of these gaps in the literature, using the dataset on collaborative projects from the ICT activity in the region of Trentino. So, from the empirical point of view, the focus of this work is a regional policy program for the development of a knowledge intensive sector that was put into place twenty years ago. However, which are the key actors inside the ICT knowledge network of Trentino that drive the innovation process? And how the knowledge flows inside, and from within and towards the region? As the Trentino RIS can be characterized as a high potential RIS, the study of the behavior of its economic agents inside the knowledge network can result in useful conclusions on the behavior of economic agents in knowledge networks of emerging knowledge intensive RIS, spatially and temporally. Consequently there are two main questions on the connectivity knowledge networks in emerging RIS that the present work answers: Which kind of proximity affects more the creating of trustful co-operations between the actors of a regional knowledge network? And in periods of uncertainty, which are the mechanisms for trust creation between actors that enhance the inertia of the knowledge network? Does the behavior of the economic agents of a regional knowledge network change during high risk periods and in which way?

1.2 The Goal of the Research

Considering the literature about RIS and knowledge networks for innovation and the evidence of growth in the ICT sector in Trentino, it appears interesting to study in depth the knowledge network of Trentino, attempting to reveal some useful insights of this growth evidence. Trentino demonstrates a significant increase in firms and employees in the ICT sector, while the rest of Italy, as well as the rest of the sectors in the same region demonstrate a decrease. So, studying in depth the case of Trentino, the literature can gain some evidence about the evolution of regional knowledge networks on ICT during periods after external negative economics events, like periods of crisis. Also, it can give useful insights to the regional policy makers for forming policies aimed at the maintenance of the regional knowledge network inertia, resilience, and growth.

Hence, the general aim of this research is to investigate the mechanisms under which the knowledge network of an emerging knowledge intensive RIS evolves in multiple dimensions. This achieved by studying in depth the data from Trentino ICT knowledge network. Initially, this research draws a conceptual framework for understanding the structure of a regional knowledge network in three dimensions.

This conceptual framework constitutes a useful tool for exploring the knowledge network and accomplishing the objectives deriving from the primary goal of the research. The first of these objectives is the structural analysis of the regional knowledge network, the identification of leading actors inside it, and the maintenance of the network inertia and resilience in case that these actors are absent. The second objective aims the exploration of the mechanisms of preferential attachment for different kinds of proximity and their effect to the creation of trust in terms of repeated collaborations (strong ties) inside the regional knowledge network. The third objective is the study of the dynamics of knowledge network and its evolution, in order to shed light to the influence of external negative events (e.g. economic crisis) to the structure of the knowledge network in a second time period.

1.3 The Solution

Despite the bulk of research on RIS and the agreement that the knowledge network is an indispensable element of the RIS, there is still a lot of ongoing research on the network evolution spatially and temporally. The present study introduces a multidimensional conceptual framework for the analysis of the Trentino ICT knowledge network, in order to describe the knowledge network in multiple levels. It identifies the flows of knowledge inside the network, and inside and outside the region, as well as, the key actors and their special role in the knowledge diffusion and the connectivity of the region in the field of ICT with other distant regions and markets. The existence of a tightly knit core of actors in the center of the network secures the resilience of the network and the knowledge diffusion, manages the flow of knowledge to the more peripheral actors, and connects the RIS with its external environment in national and international levels.

Concerning the spatial evolution of the knowledge networks, the preferences of the economic actors operating inside the regional knowledge networks, in terms of cooperation in collaborative projects and knowledge diffusion, are important. The local actors try to strengthen the knowledge network by creating trustful collaborations with other actors that have certain characteristics. Co-locating actors prefer to collaborate repeatedly, while in the same time they aim to establish collaborations with distant actors. By the organizational aspect, actors operating under the same organizational context, especially in the case that they are both knowledge intensive institutions, exchange knowledge more intensely. At the same time, profit oriented organizations prefer to establish strong collaborative relationships with knowledge intensive organizations as the latter constitute low risk and low cost knowledge sources. Finally, also the relational position of an actor inside the knowledge network matters to the establishment of strong relationships. Peripheral actors seek to strengthen their relationships with more central actors, in order to benefit from the expertise of the latter.

Introducing the temporal dimension for investigating the evolution of knowledge networks through time, this thesis analyzes the regional knowledge network of Trentino, during a high certainty period (before the economic crisis) and a low certainty period (during crisis), identifying the differences between the economic agents of the region. Hence, the trust created by previous co-operations, matters more for the agents during periods of high uncertainty. In other words, the actors of a regional knowledge network prefer to repeat successful co-operations of the past, than to establish new collaborations with actors they do not know. Simultaneously, the fact that the actors share an attribute matters less for the inertia of the knowledge network.

1.4 Innovative Aspects

The present research is the first one introducing Social Network Analysis (SNA) in the study of knowledge transfer in Trentino. To achieve this, it uses the entire universe of actors involved in the regional ICT knowledge network for the last fifteen years. It allocates this dataset to an original multidimensional conceptual framework, in order to reveal the value of the knowledge network *per se*, and the impact of the regional policies on the network and not on the output of the innovation process.

On the spatial evolution of networks, it explores in depth the behavior of the actors of a regional knowledge network, in order to make the network relationships more solid through strong collaborations. It proves that the effect of every kind of proximity or distance is different. Certain cases of distance in attributes of the actors serve better the purpose of network strengthening. Also, it introduces the measure of relational proximity, exploring the effect of the position of an actor inside the knowledge network in relation with the rest of the actors.

The major contribution, though, of this thesis is the introduction of the temporal aspect in the evolution of the regional knowledge network, and the exploration of the agent behavior during periods of uncertainty. The introduction in the network evolution of an external negative event, like economic crisis, allows the deduction of useful conclusions on how the actors behave in terms of trust and collaboration creation.

1.5 Structure of the Thesis

The following chapters explain in detail the above arguments, shedding light to the problem and research questions presented above. Chapter 2 presents in detail the literature on RIS, knowledge flows, proximity, strong ties and evolution of knowledge networks, identifying the gaps that the present work intents to cover. Chapter 3 explains the reasons why the RIS of Trentino in Italy, and especially the field of ICT was selected, the short economic history of the region and the institutional setting of Trentino. Chapter 4 presents the dataset and the method of analysis followed to treat it, comparing it to other methods of handling relational data. Chapter 5 introduces the conceptual framework of the analysis, while it analyzes the Trentino ICT knowledge network in multiple levels, identifies the key actors, and reveals their role in it. Chapter 6 argues on the spatial evolution of knowledge networks of emerging RIS, controlling for the effect of several kinds of proximity between the actors on the creation of a solid network. Chapter 7 explores the dynamics of knowledge networks through time, and compares the behavior of the economic agents of the network during high and low risk periods. Finally, Chapter 8 presents the conclusions deriving from the analysis, the scientific contribution of the present work and the policy implications that it can have, and the directions for further research in the field.

CHAPTER 2

REVIEW OF THE LITERATURE

The systemic approach in order to describe the generation of innovation exists for about three decades, being established in the literature in a short period of time by the works of Freeman (1987), Lundvall (1992), Nelson (1993) and Edquist (1997). Edquist (1997) defined the systems of innovation as "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations". The systematic approach of innovation concerns the determinants of innovation, and not its consequences (e.g. growth). The literature divides the systems of innovation in three main kinds: the National Innovation Systems (NIS) considering the innovation systems inside the national borders (Freeman, 1987; Lundvall, 1992; Nelson; 1993), the Sectoral Innovation Systems (SIS) that are focused on several technological fields and product areas (Breschi & Malerba, 1997; Carlson, 1995), and the Regional Innovation Systems (RIS) in which the boundaries are the regions within countries or include parts of different countries (Cooke et al, 1997; Asheim, 1999; Cooke, 2001).

The present research deals with the regional aspect of the systems of innovation in a specific high-technological sector. In this chapter, the blocks of the literature that are used to build the present argument, are critically reviewed. The first section (section 2.1) presents the several strands of literature deriving from the concept of RIS, their classification according to the stage of their evolution, and an analysis of the RIS as networks of interdependences and complementarities between actors and institutions. Then (section 2.2), the generation of knowledge is described as an indispensable element of the RIS existence, while its diffusion between actors causes knowledge flows and spillovers, creating a knowledge network that fosters the innovation process in the region. The detailed description of the characteristics of the actors generating and transferring knowledge in the region follows (section 2.3). The notions that are under examination and analysis in this study are the several kinds of proximity, which means how the actors are close or distant in terms of attributes, like location, institutional or organizational context, position in the network in relation with other actors. The discussion about the characteristics of the ties (relationships) between the actors of the knowledge network follows (section 2.4). The main characteristic of the several kinds of interactions between actors is their intensity and the advantages or disadvantages that it may imply. Other two interesting subjects are the mechanisms under which these interactions are initiated and the resilience that they can bring to the knowledge network of the region and consequently to the innovation process. In the end, the evolution through time of these interactions that incorporate knowledge transfer results in the evolution of the knowledge network itself, attaching to it a dynamic aspect (section 2.5).

2.1 Regional Innovation Systems (RIS)

Since 1990's, governments and supranational institutions have shifted their focus to the upgrading, development, and strengthening of the Regional Innovation Systems (RIS). This concept has widely attracted the attention of policy makers and academics as a valuable analytical tool for the studying and understanding of the innovation process within regional economies (Doloreux & Parto, 2005). The notion of RIS has not a generally accepted definition, however according to Doloreux and Parto (2005) it can be understood as “a set of interacting private and public interests, formal institutions and other organizations that function according to organizational and institutional arrangements and relationships conductive to the generation, use, and dissemination of knowledge”.

This definition stems out from two main bodies of literature. The first one is the strand of research on systems of innovation under the spectrum of evolutionary economics and theories of technological change, conceptualizing innovation as an evolutionary process (Edquist, 1997). Factors external and internal to the organization influence the innovation process, while the interactions between individuals and departments within the organization, and external collaborations with other organizations stimulate the collective learning and consequently innovation (Dosi, 1988). The second body of literature is the one of regional science which supports that innovation is a locally embedded process (Storper, 1997). According to this strand, the benefits of localization and spatial concentration include the knowledge creation and transfer that contributes to the competitive advantage of regions (Asheim & Gertler, 2004; Antonelli & Pegoretti, 2007).

So, the framework of RIS is the most commonly accepted framework in the literature studying the regional innovation process (Doloreux & Parto, 2005). The core argument supporting this conceptualization is that the regional actors do not innovate isolated, but in cooperation and interaction with other actors in the regional innovation process. This implies that the innovativeness of a regional actor is embedded in the innovation capabilities of other regional actors and the kind of relationships developed between them (Doloreux, 2002). Despite the heterogeneity of research fields that treat this framework (evolutionary, institutional, innovation, knowledge economics etc.) and the variety of terms that are used to describe, with different specificities, innovation systems (clusters, innovative millieux, industrial districts etc.) the RIS framework highlights the geographical dimension that can be bigger than a city and smaller than a nation. The RIS spans across complementary and overlapping sectors, emphasizing how regional competitive advantages relate to the spatial interconnectivity of actors and institutions (Stuck et al, 2016).

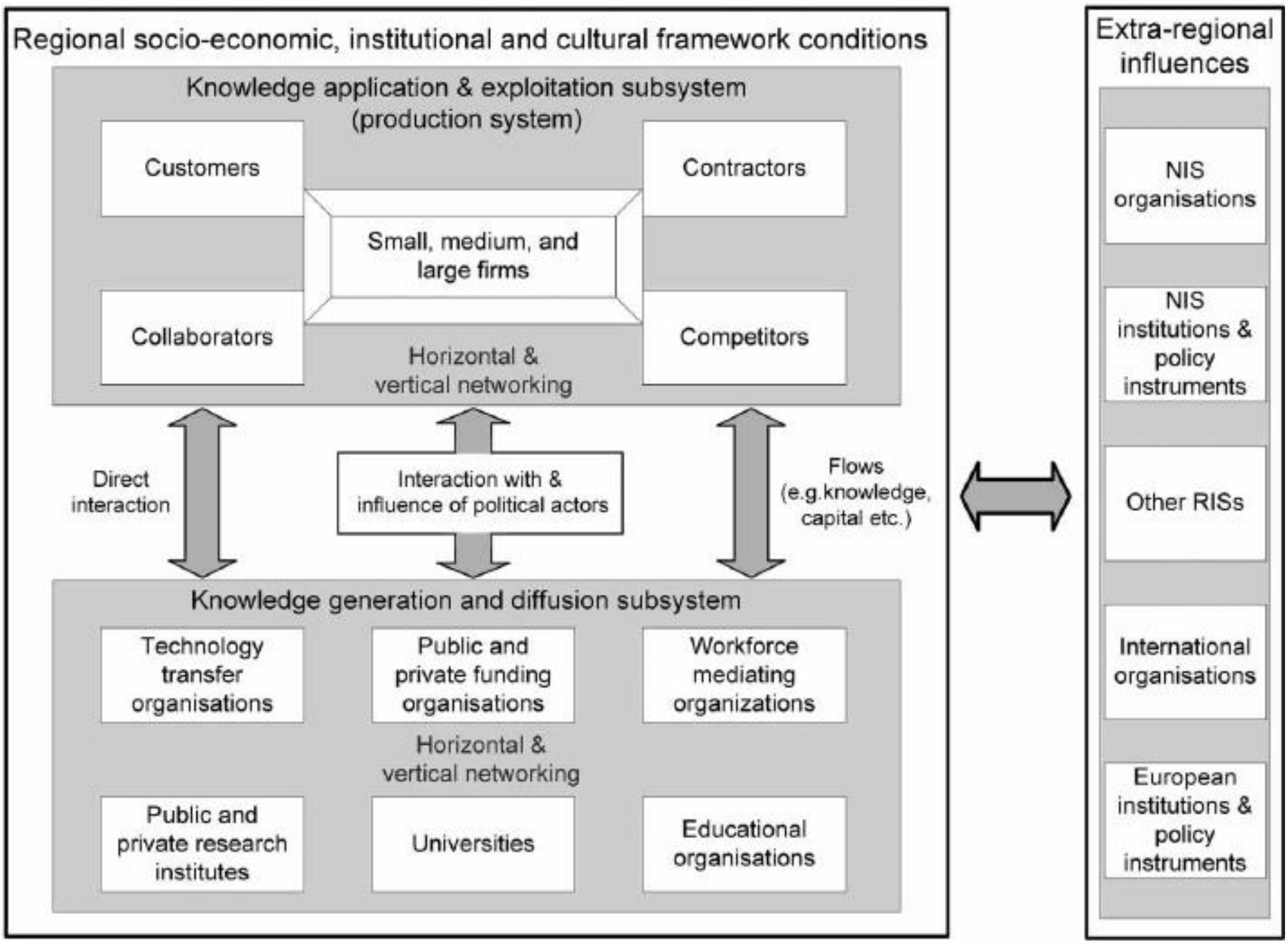

Figure 1: Schematic illustration of a regional innovation system (Stuck et al, 2016)

Stuck et al (2015) illustrated an RIS based on the conceptual frameworks described by Autio (1998) and Cooke (2002) (Figure 1). In Figure 1, the regional context and actors are divided in two main categories: those that generate and diffuse knowledge (universities, research centers, public agencies etc.), and those that apply and exploit knowledge (private firms and their environment). According to this framework, these two subsystems communicate inside the region with knowledge flows and spillovers, and simultaneously the entire RIS communicates with distant extra-regional actors (NIS, other RIS, or the market). The concern with this framework is the discrimination of actors in generating and diffusing, or applying and exploiting knowledge, as the borders of this differentiation can be very vague in terms of which actors do what. In any case, though, the RIS uses networking in order to generate, diffuse, apply, or exploit knowledge at regional, national, and international levels. However, what is clearly acknowledged in the RIS literature is that the generation and diffusion of knowledge relies on the networking of actors of different kinds, located in different places (inside and outside the RIS).

According to Cooke (2001), not all the RIS are performing in the same way. There are regions performing well in economic terms and including innovation systems that are market-led. However, there are a lot of regions in the developed countries that are suffering from market weakness or failure to several degrees. Cooke et al (1997) made a categorization of the main organizational and institutional dimensions that result to strong or weak RIS potential. The criteria according to which the regional innovation happens can be either infrastructural or superstructural.

The first infrastructural criterion concerns the level of financial endowment and autonomy of a region. In other words, how much the regional government facilitates the interactions between actors, public and private, through a regional credit-based system, including the available national or international (EU) funds. This, results to reputation, capability, reliability, and trust among the regional actors.

The regional public budgets are important as well. According to Cooke (2001), they enhance the regional innovation potential and are of three kinds. The first competence is the decentralized spending, in which the region is the main channel through which the national government finance certain actors. The second competence is the autonomous spending, in which the regional government decides how to allocate funds. In the third competence, the taxation authority, the regional government is free to decide which actors to support and additionally is able to design special policies to support regional innovation. This last competence constitutes a stronger base for the promotion of regional innovation.

Another infrastructural criterion is the ability of the regional government to either control or influence investments in the infrastructures (transports, telecommunications, universities, research centers, incubators). The capacity of every region in the same or different countries differs in terms of financial ability to construct infrastructures. The more influence the regional government has on infrastructures, the higher is the RIS potential of the region.

The group of superstructural criteria can be divided in three dimensions: institutional dimension, organizational dimension for firms, and organizational dimension for governance. Analytically, the characteristics of these three dimensions are illustrated in Table 1 (Cooke, 2001).

In all their three dimensions they refer to the mentality of the regional actors, helping to define the level of embeddedness of the region, its organizations and institutions. According to Dosi (1988), embeddedness is the degree to which a community operates under shared norms of co-operation, trust, and 'untraded interdependencies, and does not demonstrate competitive, individualistic, and hierarchical behavior. The first group of characteristics enhances the capability of a region to innovate through networking and co-operating.

Table 1: Conditions for higher and lower regional innovation systems potential (Cooke, 2001)

Higher RIS Potential	Lower RIS Potential
Infrastructural Criteria	
Autonomous taxing and spending	Decentralized spending
Regional private finance	National financial organization
Policy influence on infrastructure	Limited influence on infrastructure
Regional university-industry strategy	Piecemeal innovation projects
Superstructural Criteria	
Institutional Dimension	
Co-operative culture	Competitive culture
Interactive learning	Individualistic
Associative – consensus	Institutional dissension
Organizational Dimension (firms)	
Harmonious labor relations	Antagonistic labor relations
Worker mentoring	Self-acquired skills
Externalization	Internalization
Interactive innovation	Stand-alone R&D
Organizational Dimension (governance)	
Inclusive	Exclusive
Monitoring	Reacting
Consultative	Authoritative
Networking	Hierarchical

So, in the institutional dimension the regions that display co-operative culture, interactive learning, and quest for consensus result to RIS with higher potential. The same happens in the organizational level for the firm; the RIS with higher potential are considered those with harmonious labor relationships, worker mentoring, externalization, and interactive innovation. Finally, in the organizational dimension for governance, higher potential is displayed in RIS that are inclusive, monitoring, consultative, and networking.

In any case, the classification presented in Table 1, cannot be absolute and represents the ideal conditions under which an RIS with high potential develops. However, every region demonstrates a tendency to the one or the other edge, resulting to a more or less systematic RIS.

As said before, all the works focused on the RIS stress out the importance of networking as an indispensable element of a successful RIS. This literature suggests that all the actors of an RIS benefit from regional networking (Asheim, 1994). This is due to the knowledge transfer occurring from flows and spillovers which spring out from this networking and will be analyzed in the following section of this chapter. Although the literature until recently tends to treat these benefits equally for every region, assuming that all the regional actors are equally embedded to the regional network, empirics have presented strong insights about the existence of significant heterogeneity in this embeddedness (Giuliani & Bell, 2005; Boschma & ter Wal, 2007). Stuck et al (2016) argue on this subject, analyzing the concept of RIS by the network perspective, and more specifically from the point of view of knowledge networks. In this way they argue on the influence of institutional and governance factors on the interactions of the RIS actors.

To accomplish this, Stuck et al (2016) use the conceptual framework of Cooke (2004) that classifies the RIS according to their business and governance characteristics. In the business dimension, an RIS can be either localist, interactive, or globalized, while in the governance dimension, an RIS can be grassroot, networked, or dirigiste. This distinction results in nine theoretical types (Figure 2), although the three diagonal ones can be considered as the “ideal cases”, as the characteristics of these cases are more distinguishable.

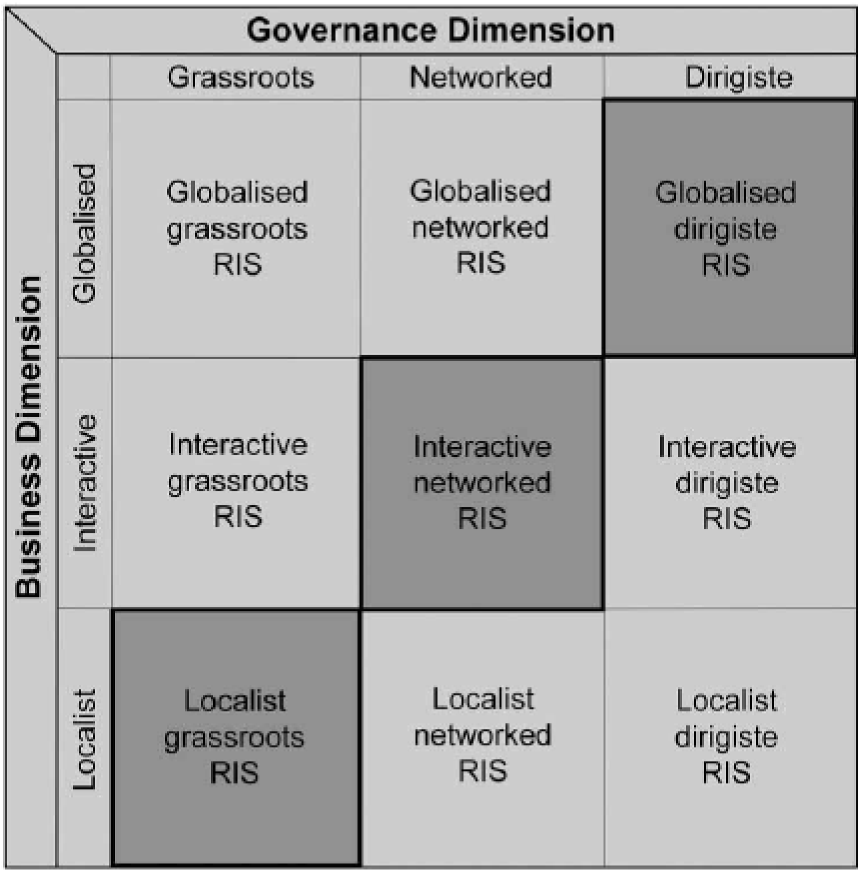

Figure 2: Types of regional innovation systems (Stuck et al, 2016)

The central case, the interactive networked RIS is considered the ideal RIS kind. The governance of this type is networked implying a multileveled point of view considering the policy and business governance (regional, national and international levels) (Cooke, 2004). The business dimension of this type demonstrates a balanced engagement in the R&D activity of small, medium and large firms, as well as higher-education and research institutes. In this type of RIS the regional actors tend to collaborate intensely and try to participate actively in the knowledge networks. The localist grassroot RIS in the governance dimension is organized at the regional level, while innovation process is managed by regional actors (Cooke, 2004). In the business dimension, in this type of RIS, one or more small industrial districts inside the region appear, their actors is in majority SMEs, while the engagement of these SMEs in the R&D and knowledge relations is rare, as they are interested in spontaneous and industry specific support (Asheim & Coenen, 2005). These SMEs remain competitive through flexible production, strong specialization and labor division, and tacit knowledge based innovation process. The third type of RIS described by Stuck et al (2016) is the one of globalized dirigiste RIS. In this third type, the governance is strongly influenced by actors outside the RIS, like national governments (Cooke, 2004). In the business dimension, this type is characterized by one or more industrial districts or clusters dominated by the presence of a multinational enterprise or a governmental research institute (Asheim & Isaksen, 2002). This is a dominant actor in knowledge transfer in the region and organizes the network according to its needs (Assimakopoulos et al, 2016).

Despite this theoretical classification of RIS according to their networking characteristics, these borders continue to be vague and need further research. RIS consist of a big amount of relationships between a variety of actors with different degree of embeddedness that constitute complicated multileveled networks that can demonstrate different characteristics. However, successful RIS with high potential can have a tendency towards one or another type presented here.

2.2 Knowledge Flows and Spillovers

The significant role of knowledge and knowledge networks in the innovation process of regions is central in the literature on RIS. Regions use knowledge to create competitive advantage (Asheim et al, 2007; Antonelli & Pegoretti, 2007). Innovation and knowledge are interactive and cumulative processes, contingent on the institutional context. Although the terms 'knowledge-based' or 'learning' economy are frequently used to describe an RIS, the knowledge itself does not affect economic growth. It has to be included into the production of the region through innovation (Fischer & Frohlich, 2013). Thus, the capacity of the regions to incorporate knowledge and produce innovation varies substantially. The knowledge base on which innovation is produced varies in different industries and regions (Asheim & Coenen, 2005). Also, every region for innovating successfully has to incorporate a mixture of complementary knowledge bases. So, the innovation in a region is a process that is clearly depending on the accumulation and/or creation of a wide variety of knowledge (Fischer & Frohlich, 2013).

For analyzing knowledge creation and diffusion inside RIS, it is necessary to define knowledge first. The definition of knowledge varies considerably in each strand of literature. A really generic definition is that knowledge is the result of learning and experience, involving information or data (Fischer & Frohlich, 2013). In economics there are two bodies of literature, the first defining knowledge as an object in terms of information theory, while the second views knowledge as process embodied to individuals or actors. The literature on knowledge inside RIS mainly follows the second view. So, the knowledge is considered as a process that implies the capability of using information inside the specific environment of each agent and generates additional information (Antonelli, 1999). The creation of new knowledge is considered mostly the outcome of the learning process of innovators, which is highly-localized and embedded to the agents (Winter, 1987; Nelson, 1993).

Knowledge in general is classified in two main categories: explicit (or codified) and tacit knowledge. The first category refers to knowledge codified in documents. So, the codification implies that knowledge is transformed to ‘information’ easily transmitted. This process makes easier the transfer, verification, storage and reproduction of knowledge. The main characteristics of codified knowledge are that it is compact and standardized. Thus, codified knowledge can be easily transferred over long distances and across borders at low cost (Foray & Lundvall, 1998). Codified knowledge can be treated as a good, sold and bought in the market, however, this procedure is difficult as the buyers don’t know in advance what are they buying. On the other hand, tacit knowledge refers to knowledge that cannot be easily transferred as it is not stated in explicit form, like skills or beliefs (Polanyi, 1958). This kind of knowledge is embodied in the individuals, so it cannot be traded at all in the market, while its transfer is extremely embedded to the social context (Foray & Lundvall, 1998). Codified and tacit knowledge are complementary, as the knowledge codification is never complete, despite the technological advances, and the tacit knowledge will continue play important role in the innovation process.

In the last decades, with the technological advances the border between tacit and codified knowledge has changed, so the recent literature treats knowledge as a whole. Antonelli (2006) refers to the features of this knowledge that is embedded to regions and gives heterogeneity in their knowledge base. These features are the levels of tacitness, indivisibility, complementarity, and appropriability. As mentioned above different levels of tacitness of knowledge can be identified. Knowledge can be highly tacit when it is fully embodied to agents (individuals and organizations), so it cannot be transmitted to third parties. Knowledge also can be considered highly codified when it is fully translated in a consistent code. In between these cases, part of knowledge can be explicitly articulated, so some levels of tacit knowledge characterize also codified knowledge. In terms of indivisibility, there is weak indivisibility when every module of knowledge is self-contained, while there is strong indivisibility when different modules of knowledge have high interdependence. This feature refers to types of relationships between agents that indicate and bear different modules of knowledge which are necessary for the composition of new knowledge. The third feature is the complementarity of knowledge. The complementarity refers to the agents of the region that contribute with their attributes to generate, transfer and apply knowledge. Finally, the knowledge appropriability refers to the ability of the agents to be benefited by the economic advantages that stem from the generation of knowledge. This feature of knowledge depends on the institutional and market conditions (Antonelli, 2006).

The notion of knowledge is strongly embedded in the RIS literature, as regional resources are included in a particular place-specific context of knowledge of both tacit and codified nature (Asheim & Isaksen, 2002). Thus, Asheim et al (2011), present a differentiation of knowledge that is used as input in new knowledge generation and innovation in RIS. The authors differentiate the knowledge in analytical, synthetic, and symbolic. The analytical knowledge refers to activities where the scientific knowledge is important to be modeled and codified, such as the fields of biotechnology and nanotechnology. In this type the knowledge networks play an important role, without implying that tacit knowledge is not necessary. The reason of the high codification of knowledge is that scientists are based on previous projects, reports and patents to create new knowledge. The synthetic knowledge is involved mainly in economic activities, where the innovation happens due to the application or new combinations of already existing knowledge. This type of knowledge happens inside the industry through R&D activities that are called to reply to specific questions and create innovation according to the requests of the clients or the suppliers. Here networking is also important but in the field of product development than in basic research. Symbolic knowledge refers to the creation of meaning, desire, and aesthetic attributes of products for economic use. This type is characterized by an intense tacit component, as it is embedded to the creators. It does not concern so much research itself (know-how) but mostly concerns the quest of the right professionals (know-who).

In all cases and classifications mentioned, the element of networking appears to be important for the creation of new knowledge and its transfer. Regional knowledge generation and transfer can be depicted as network of actors inside the RIS that are interacting between them. Interacting actors can be depicted as nodes and the relationships between them that indicate knowledge transfer as ties. The networks of knowledge facilitate as channels and conduits the knowledge flows and spillovers for the creation of new knowledge (Owen-Smith & Powell, 2002; Boschma & ter Wal, 2007; Giuliani, 2007; Whittington et al, 2009; Gertler & Levitte, 2005). A big part of the literature on RIS was occupied with the modules of knowledge transferred through the network, naming them either spillovers or flows. Both terms indicate a movement of knowledge from one actor to another (individuals, organizations, regions). These terms are almost synonymous raising an ongoing debate of academics preferring one of them. The main difference between the two terms is that spillovers imply a spontaneous influence in terms of knowledge of the actors due to their colocation (Jaffe et al, 1993; Breschi & Lissoni, 2001; Maurseth & Verspagen, 2002; Iammarino & McCann, 2006), while the flows imply a purposed and directed path of knowledge from one actor to the other (Jaffe & Trajtenberg, 1999; Dahl & Padersen, 2004; Breschi & Lissoni, 2009; Agrawal et al, 2006; 2008).

All, knowledge networks, flows, or spillovers are used as concepts to investigate the knowledge birth and transfer inside the regions. One of the key features of RIS is the creation of local knowledge that is non-articulated explicitly among the organizations of the RIS. If the knowledge produced inside the RIS is combined with knowledge of other regions or markets, an added value can be created, fostering innovation both locally and globally (Bathelt et al, 2004). According to Bathelt et al (2004), there are three levels of knowledge creation: inside the firms, inside the RIS and pipeline creation.

Initially, knowledge is created within organizations, through the effective division of labor in departments or projects (Maskell & Lorenzen, 2004). However, the organizations trying to balance the division of their labor build external relationships and this is the second level of knowledge creation that appears within the RIS. Localized learning (the so-called local buzz) plays an important role in the process of growth and innovation, and results in the production of new knowledge, economic specialization, and urbanization of economies (Bathelt et al, 2004; Asheim et al, 2007; Shearmur & Doloreux, 2008). The local buzz inside the RIS consists of continuous updates in information, learning, and knowledge that stimulate the conventions and other arrangements in the innovation system. Thus, the spatial proximity of the organizations of the RIS is necessary for the development of mutual trust relations based on a shared experience of interactions. However, just being co-located is not sufficient, because new knowledge does not enter into the RIS, so this can lead to lock-ins, as the local knowledge resources can get completely exploited and new knowledge is not created into the RIS.

The solution to the lock-in problem is the creation of pipelines; channels that create flows of knowledge through partnerships of inter-regional or international spectrum (Powell & Owen-Smith, 2002). Compared with the local buzz, the creation of pipelines is not automated and spontaneous, but the amount and the kind of knowledge transferred through them is monitored and controlled by the degree of trust between the actors (Maskel & Malmberg, 1999). The main reason for the creation of the pipelines is that often an RIS is not able to offer all of the framework conditions, knowledge, and institutions needed for innovation. So, it has to cooperate with other regional or national systems in order to gather the needed resources (Cooke et al, 2004). In this way, RIS become open and globally connected (Carlsson, 2006; Cainelli et al, 2012).

Both local buzz and external pipelines offer advantages to the actors of an RIS, when the second are carefully created and maintained. Since not all the necessary resources for innovation can be found locally, and especially those which involve tacit knowledge, formal and informal networking seems to be a solution for the resource problem. Through social networks, the actors of an RIS know where to obtain these scarce resources and how to link up with them. In this context and in this research, the social network aspect highlights the important role which social and business links play in the fostering of regional growth (Granovetter, 1973; Iammarino & McCann, 2006)

The literature has produced until now several conceptual frameworks in order to describe knowledge spillovers and flows inside, from within and towards the RIS (Cooke, 2001; Fischer, 2001, Bathelt et al, 2004). The boundaries and institutional framework of RIS were set two decades ago by classifying the RIS according to their characteristic and potential (Cooke et al, 1997; Cooke, 2001).

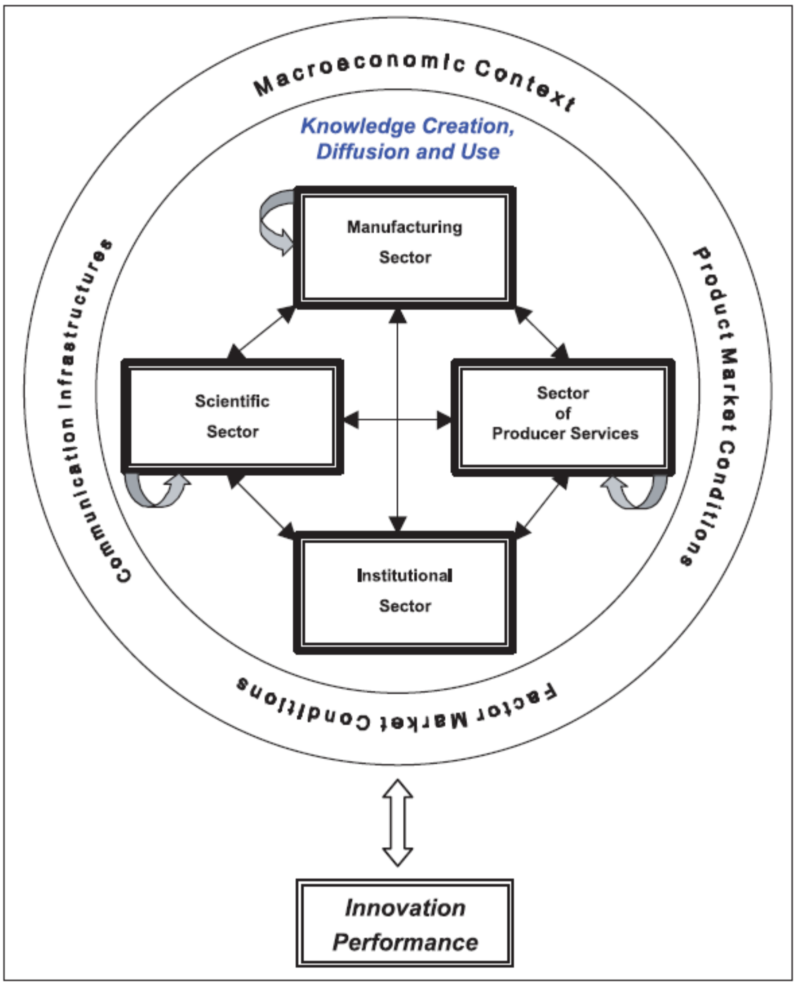

Figure 3: The major building blocks of a system of innovation (Fischer, 2001)

A generalized framework was introduced by Fischer (2001), dealing with the localized input-output relations, the knowledge spillovers, and the interdependencies between the actors of the RIS. This framework presents the major building blocks of a system of innovation (Figure 3), however it cannot help with the micro analysis of the knowledge relations developed inside the RIS. More focused on knowledge transfer issues is the framework provided by Bathelt et al (2004). Although, the authors talk about clusters, they introduce the notion of knowledge transfer and the differentiation between local and extra-local relationships (Figure 4). Still, they focus on the geographical proximity of the actors and the framework cannot describe the multiple kinds of relationships in different levels of analysis. Thus, there is need of a multidimensional framework in order to depict the dynamics developed inside the RIS and the spillovers that possibly these dynamics produce.

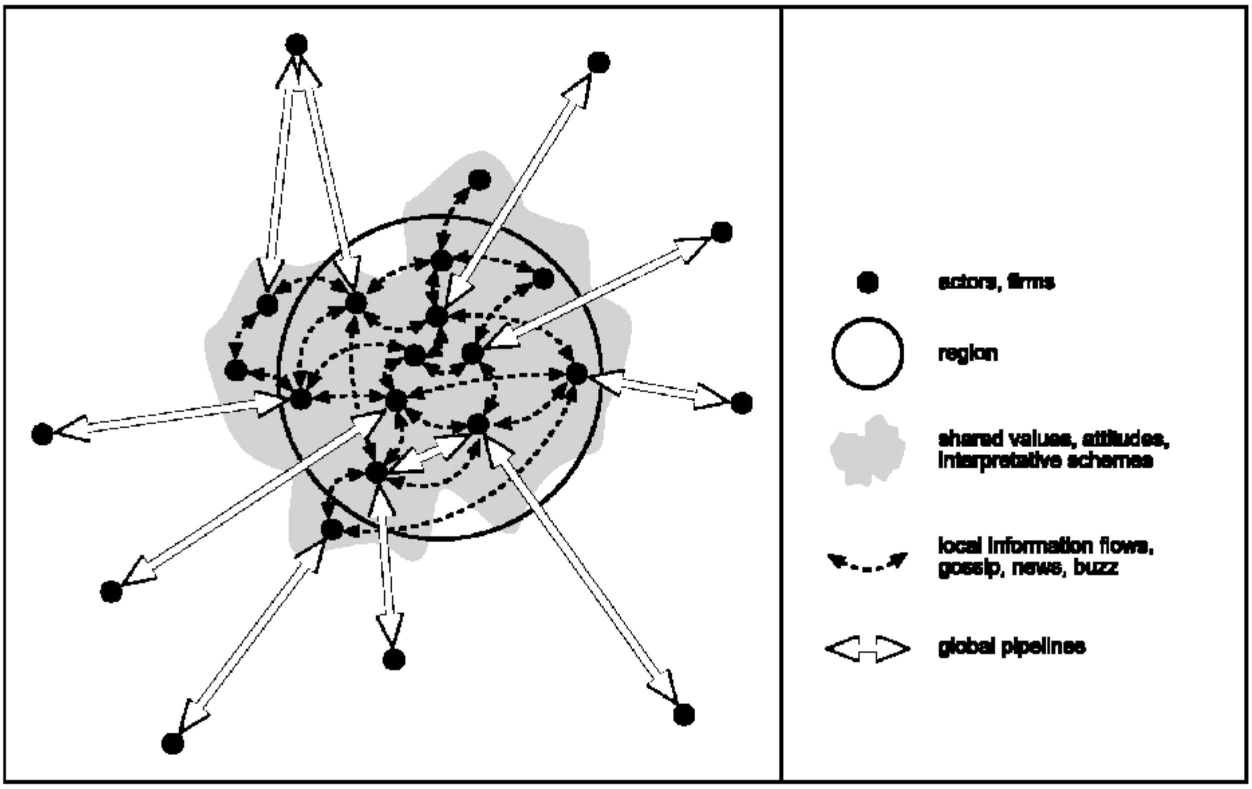

Figure 4: The structure and dynamics of local buzz and global pipelines (Bathelt et al, 2004)

2.3 The Strength of Strong Ties and Network Resilience

In this context and in this research, the social network aspect highlights the important role which social and business links play in fostering regional innovation and economic growth (Granovetter, 1973; 1983; Iammarino & McCann, 2006). The network of the actors, according to the literature in the research area of innovation, is central to the process of knowledge creation and transfer (Inkpen & Tsang, 2005; Rost, 2011). These relationships can be, of course, more or less intense.

The most frequently used measure of tie strength, in the literature, is the one of Granovetter (1973; 1983), who simply used the frequency of interaction to approach the tie strength. In this way the ties can be distinguished in strong and weak in relative terms. Granovetter (1973; 1983) reported four properties that identify a strong tie: the amount of time (or frequency of interaction), the emotional intensity, the intimacy, and the reciprocal services.

However, there is an ongoing debate on the value of weak or strong ties based on Granovetter’s work. The strand supporting the importance of weak ties claims that weak ties provide actors with access to information and resources beyond those that they can find in their close social circle or collaborators (Levin & Cross, 2004). This kind of ties is useful for the innovation systems, especially on high-technology, that seek for specialized knowledge and resources in distant markets, so they have to make experiments by creating ties with actors they have not cooperated with before. On the other hand, the strong ties give greater motivation to the actors and are more easily available (Rost, 2011). Strong ties are likely to be more useful to an agent, when this agent is in an insecure position. So, in case of a negative event that brings an actor to a high risk position, this actor is expected to turn to the already successful collaborations. Thus, actors in insecure or high-risk positions are more akin to invest in the development of strong or stronger ties for protection, uncertainty reduction, and dealing with crises (Granovetter, 1983; Krackhardt & Stern, 1988).

Strong ties constitute a base of trust that can provide comfort in a phase of uncertainty, like a generalized economic recession. This transition period after a negative event is not facilitated by the weak ties but by the strong ones (Krackhardt et al, 1992; Rost, 2011). The repeated collaboration with a set of actors provides to the agent knowledge-based interorganizational trust that is deepened by the time and the intensity. This consequently stimulates reciprocal trust. Thus, a long duration of this mutual relationship, allows the actors to accumulate knowledge and reinforce over time, thereby the tie is strengthened (Capaldo, 2007; Levin & Cross, 2004). Trusting relationships make easier the transfer of exclusive knowledge (i.e. knowledge held only by the members of a community) (Uzzi, 1996; MacFadyen et al, 2009). Moreover, more detailed, tacit and holistic knowledge can be efficiently transferred by trusting relationships, so this helps in problem solving (Uzzi, 1996; MacFadyen et al, 2009). The mechanisms under which this trust and the strong tie between the actors are reinforced during periods of uncertainty, remain still to be explored by the literature, and constitute one of the aims of the present study.

The repeated co-operations and the strong ties, place certain actors of the RIS in key and more central positions inside the knowledge network (Ferrary & Granovetter, 2009). There are different types of these kinds of actors that in some RIS are leading actors that can participate in decision, and in other RIS simply motivate the innovation process and play supportive role in the regional policy formation. These actors are called 'anchor' actors from the literature (Agrawal & Cockburn, 2003). Agrawal and Cockburn (2003) name this actor as 'anchor tenant', a term used originally to describe a large department store with a recognized name in a retail shopping mall that creates traffic in the mall, increasing the sales of the rest of the shops. According to the authors, in RIS theory, the anchor tenant is a large, locally present firm that is R&D oriented and stimulates the innovative activity in the region. However, in the case of the present research, the term anchor will characterize any organization public or private, that stimulates with its reputation the innovative activity in the RIS, enables knowledge transfer, and creates the necessary trust and certainty for the rest of the actors inside the regional knowledge network.

Another important element of knowledge networks in terms of actors is the presence of bridging actors that are called brokers. This type of actors make a connection to isolated sources of knowledge, or in other words connects otherwise disconnected parts of the knowledge network. In this way local brokers create an advantage for themselves and for the region (Burt, 1992). So, brokers are importing knowledge inside the RIS from distant markets and RIS. There is an argument about these bridging actors, according to which they are adding to the value of knowledge in the network during safe and low-risk periods, while during uncertainty periods regional actors are searching for knowledge in actors that inspire trust through previous collaborations. Empirical research showed that cohesion (repeated cooperation in cores) and brokerage are more complementary in regions than in conflict, when they are combined in a productive way (Fritsch & Kauffeld-Monz, 2010).

Talking about strength of ties, is unavoidable the reference to the importance of strong dyads inside the knowledge network of a region. Dyads are pairs of organizations that are connected through strong ties. These dyads can be characterized of homophily (proximity) or heterophily (distance) (Rivera et al, 2010; Assimakopoulos, 2007). In these cases it is not just an anchor actor that affects the development of the network but a dyad of them that cooperate closely. Similar are the notions of triads and cliques. These are groups of actors inside the knowledge network that cooperate intensively with each other, however, ideally not inclusively (Wasserman & Faust, 1994).

According to the way that knowledge diffuses inside the regional network, different network structures are emerging (Cowan & Jonard, 2004). There could be a variety of them in the same knowledge network, depending on the type of relation that indicates knowledge transfer under investigation (Pegoretti et al, 2012). The structures of knowledge appearing in the present study are analyzed extensively in Chapter 4. So, the structure and the key elements of the network mentioned above play a significant role to the resilience of the network.

Resilience is the ability of a system to cope with negative change. More specifically, network resilience is "the ability of a network to defend against and maintain an acceptable level of service in the presence of challenges" (Smith et al, 2011). So, network resilience is a crucial discussion for a lot thematic areas, such as information and network security, fault tolerance, software dependability, and network survivability. However, it appears to be a new discussion topic in social, innovation and knowledge networks. In the case of a knowledge network, the term resilience refers to the case that one or more actors stop interacts completely with other actors inside the network, due to an external or internal negative event. So, if the knowledge is transferred as before the absence of the node with its interactions, then the resilience of the knowledge network is maintained (Adamic et al, 2001). Hence, when a knowledge network maintains its resilience, it anticipates, prepares for by responding and adapting to radical changes and sudden failures of actors, in order to survive and prosper.

In terms of topology there are few attempts in the literature that try to explain the network resilience, while it is usually used to as a measure to describe the properties of the network (Magioni & Uberti, 2009; Suire & Vicente, 2013). This justified as the regional, national or sectoral knowledge networks significantly differ considering the behavior of their actors. However, the majority of this recent literature focuses on the effect that a failure in the knowledge network may have in the resilience of the RIS (Crespo et al, 2014), and how a resilient regional knowledge network can result in regional advantage (Asheim et al, 2011; Boschma, 2015). The network resilience is not synonymous to the regional resilience; however the regional knowledge network constitutes a central element of the RIS, so a shock or a failure in the regional knowledge network may affect significantly the resilience of the RIS.

The global economic recession was a shock for the national and regional economies worldwide. The economic literature treated the crisis at the regional level involving the notion of resilience. The regional resilience notion comes from the engineering and environmental fields, representing the ability of the system to deal with shocks by anticipating them, responding to them, or returning to its previous equilibrium. There are three types of resilience (Martin, 2012): the engineering resilience, in which a system returns to its previous equilibrium after it was disturbed by a shock; the ecological resilience, defined as the scale of shock that a system can absorb before it is destabilized, moving to a different equilibrium; and the adaptive resilience, in which the system reorganize itself in order to anticipate or react for minimizing the impact of the shock.

The concept of resilience in the regional analysis has been extended to include the adaptability of the region (Hassink, 2010) and its long-term ability to develop new paths for growth (Boschma, 2015). A large number of empirical studies attempted to assess the existence, definition and measurement of the regional resilience. A strand of it focuses on the special asymmetries in the reaction of the region to an external shock (Cellini & Torrisi, 2014; Fingleton et al, 2012; Sensier et al, 2016), while another strand attempts an assessment of a conceptualization of this reaction and the determinants of the shock. Groot et al (2011) analyzes the factors that diversify the levels of sensitivity of different countries and regions. Martin et al (2016) demonstrated the rise of the region-specific factors and the decreasing role of the economic structure, while Fratesi and Rodriguez-Pose (2016) that the protected economies before the crisis were not protected from the crisis itself.

This research aims to cover certain gaps in the literature on knowledge networks, knowledge generation and transfer inside the RIS, and the dynamics governing the knowledge network evolution through time. Considering the fact that knowledge networks are complex and multidimensional entities, scholars attempted to express diagrammatically or analytically the process of knowledge generation and transfer in such networks (Fischer, 2000; Bathelt et al, 2004). Despite the discussion on how knowledge spillovers and flows can be traced inside the RIS and represented, all agree in the importance of knowledge network to the innovation process. I propose in this research a simple schematic representation of the knowledge network in three axes (Chapter 4): the vertical one has to do with the range of the network in space, starting from global ties and reaching to the ego-networks or anchor actors, the horizontal axis considers the knowledge network as the sum of formal and informal relationships that indicate knowledge transfer, and the time axis that represents the evolution of the knowledge network in depth of time.

After allocating the data from Trentino to this conceptual framework, the following questions arise which are aimed to be answered in Chapter 5. Which is the structure of the knowledge network in each one of its expressions? How the network structure affects the transfer of knowledge inside the regional network? Which are the key (anchor) actors in the case of Trentino ICT network? How a possible failure of one or more anchors would affect the knowledge transfer and consequently the innovation procedure in the RIS of Trentino?

2.4 Proximity Aspects

A key chapter in the literature on knowledge networks and RIS is how the agents in a regional knowledge network choose other agents for the creation and transfer of knowledge. This happens because of similarities in the attributes of actors which is called homophily or, in the innovation literature, proximity (Borgatti & Foster, 2003; Asheim & Isaksen, 2002; Inkpen & Tsang, 2005; Boschma, 2005). A big debate was raised in the literature about the effects of proximity in the RIS network (Breschi & Lissoni, 2001; Cantner et al, 2010; Balland et al, 2014). The scholars argue also in the definition and the dimensions of proximity, however they all agree that proximity is needed in some (although not necessarily all) of its dimensions for connecting the actors of an RIS and enabling the knowledge flows and innovation (Boschma & Frenken, 2010).

In terms of strength of the ties that is discussed in the previous section, the literature argues that the similarity in the attributes of the actors is also important for the development of trust between the actors (Boschma 2005; Boschma & Frenken, 2010; Balland et al, 2014). Thus, in line with this literature, the overall proximity affects positively the existence of repeated interactions inside the knowledge network, and consequently increases the trust between the actors. Actors prefer to cooperate with other actors of similar characteristics. So, the question that stems from this strand of literature is how the trust between actors is affected. More specifically, which kind of proximity creates more repeated collaborations and consequently more trustful interactions? Which kind of organizations inside and RIS feel more secure to collaborate with each other? And finally does the position, central or peripheral, play a role in trust and collaboration creation? Hence, considering this line of reasoning the following hypothesis arise:

H1: The overall proximity affects positively the repeated collaboration between two actors in a regional knowledge network. In other words, the actors that are more proximate are more probable to repeat the collaboration between them.

Although the majority of the literature with the term proximity refers mostly to geographical proximity, two actors in a knowledge network can demonstrate proximity although they are not geographical close. So, there are different kinds of proximity that the related literature classified in several categories (Gilly & Torre, 2000; Torre & Rallet, 2005). The most popular classification is the one by Boschma (2005) who proposed five dimensions of proximity that affect the propensity of actors to exchange knowledge and innovate. The same classification is followed by Broekel and Boschma (2012). These dimensions are cognitive, organizational, social, institutional, and geographical proximities. The main claim is that geographical proximity is neither a necessary nor a sufficient condition for knowledge transfer and innovation. Another argument is that the effect of geographical proximity is more obviously expressed through other kinds of proximity. This argument was empirically confirmed by Breschi and Lissoni (2003) and Ponds et al (2007), especially for social, institutional, and cognitive proximities.

Geographical proximity is represented by the physical distance of two actors, and plays important role in facilitating the other kinds of proximity. Geographical proximity can also directly affect the probability that two actors exchange knowledge (Broekel & Binder, 2007). It is strongly claimed by the literature that geographical proximity is the initial reason for the formation of relationships and networks, as close geographical distance is implying a lot of interaction between co-locating actors (Hoekman et al, 2009). Geographical proximity is beneficial for innovation, as tacit knowledge transfer requires face-to-face interaction. A reason for this to happen is the preexisting trust of interactions between the co-locating actors (Fitjar & Rodriguez-Pose, 2014). However, although the geographical proximity increases the likelihood of regional cooperation, in the same time, the exclusive cooperation between local actors may also reduce the innovative performance and result to knowledge lock-in inside the region (Broekel et al, 2010). In the empirical literature, the geographical proximity is measured by the geographical distance between two actors (Giuliani & Bell, 2005; Sorenson et al, 2006; Broekel & Boschma, 2012; Broekel, 2015), travel time (Ejermo & Karlsson, 2006), or by categories of geographical proximate actors; like inside the country, neighboring countries and the rest of the world (Ponds et al, 2007; Hansen, 2015) or just local and non-local (Boschma & ter Wal, 2007). The present work follows the latter simplified method to express the notion of geographical proximity. It distinguishes the actors in local (inside the region under study) and non-local (national and international actors), since the region under research is relatively small. From the literature derives that geographical proximity may have stronger effect to the increase of trust and repeated interactions than other kinds of proximity. Actors prefer to collaborate intensively with co-locating actors, as they prefer to trust organizations with which they can have “face-to-face” contact. This line of reasoning leads to the following sub-hypothesis:

H1a: The geographical proximity between two actors affects positively the repeated collaboration between them.

Cognitive proximity is the degree of overlap of two actors in terms of their knowledge bases. Actors in RIS search other actors proximate to their knowledge base, which either creates opportunities or sets constraints for further knowledge creation. This implies that knowledge and innovation are cumulative processes involving high degree of tacit knowledge (Boschma, 2004). The cooperation between actors implies that knowledge is dispersed among different organizations (Antonelli, 2000). So, although actors are searching of cognitively similar actors to share knowledge, if the knowledge base of two actors is too similar, the probability that they innovate in terms of recombining their acquired knowledge is lower than when not so similar knowledge bases are merged (Nooteboom, 2000). The optimal degree of cognitive proximity depends on the need of the organizations to stimulate innovation through recombination of ideas, keeping some cognitive distance, and to enable effective communication and knowledge transfer, securing an amount of cognitive proximity. The concern with high degree of cognitive proximity is that the actors risk of weakening their competitive advantage against the network partner with which they exchange knowledge (Nooteboom et al, 2007; Boschma et al, 2009; Boschma & Frenken, 2010). Thus, cognitive proximity may increase both the knowledge creation and transfer through the joint learning of the agents. Hence, it brings the agents to more similar knowledge bases (Balland et al, 2015). To measure the cognitive proximity, empirical studies use proxies such as technological profiles deriving from patent data (Nooteboom et al, 2007), statistical classifications of economic activities, like NACE codes (Broekel & Boschma , 2012; Broekel, 2015), or industrial classification with digits (Boschma et al, 2009; Boschma et al, 2012a; Boschma et al, 2012b) . In the present study, the control for cognitive proximity was not included, as there were no data for the classification of the knowledge base of all the projects. This classification exists for European Commission funded projects but not for regional or private funded projects. Although, the exclusion of the national and regional projects would mean a loss of information, the control of cognitive proximity of the actors could give opportunities for future research.

A broad definition of organizational proximity is that it is the degree of similarity of actors in organizational terms. However, this concept suffers from a high level of conceptual ambiguity. According to Torre and Rallet (2005) two actors are organizationally proximate when “their interactions are facilitated by (explicit or implicit) rules and routines of behavior and that share a same system of representations or set of beliefs". Boschma (2005) defined organizational proximity as "the extent to which relations are shared in an organizational arrangement, either within or between organizations". This definition involves the degree of autonomy and control of the organizational arrangements. Organizational proximity is assumed to help the knowledge exchange and reduce the transaction costs. However, too much organizational proximity may harm the interactive learning, as it constrains flexibility. Another way to define organizational proximity, which is used in this empirical research, is the level to which organizations are close in terms of routines and incentive mechanisms (Metcalfe, 1994). Usually, in innovation studies, there is a distinction between profit and non-profit organizations, or private and public (Cantner & Graf, 2006; Broekel & Boschma, 2012; Capaldo & Petruzzelli, 2014). This literature divides the organizations between profit (firms) and non-profit (universities, research centers, associations etc.). Alternatively, the organizational proximity can be measured in terms of subsidiaries of the same parent organization (Balland, 2012; Broekel & Graff, 2012; Balland et al, 2014; Broekel, 2015). This applies to large firms with sub-units and to universities and research centers with multiple institutes. The present research follows the first distinction but in a more detailed way in terms of organizational incentives. The profit organizations are distinguished in large firms and SMEs, while the non-profit organizations are distinguished in universities, research centers, public agencies, and other types of organizations. So, in line with the theory of organizational proximity, it is assumed that universities and research centers feel safer by creating strong ties between them, as the collaborations between them constitute a low-uncertainty and low-cost source of expertise and knowledge inside the region, leading to the following hypothesis:

H2a: In regional knowledge networks, organizational proximity between two universities or two research centers affects positively the repeated collaboration between them.

In general, actors prefer to cooperate with actors under the same organizational context. Non-profit organizations for example prefer to cooperate with other non-profit organizations, but this has a negative impact to cases with organizational distance. The most common case of organizational distance in the literature is the one of 'triple helix' (Etzkowitz & Leydesdorff, 1995; Leydesdorff & Etzkowitz, 1998) which describes the relationships developed between academia, industry and state. Alternatively, in the literature defining organizational proximity by subsidiaries of the same parent organization, the organizational distance is defined by organizations that do not share the same funding organization (Broekel, 2015). The present research makes an attempt to control for the effect of the organizational distance on the trust developed from previous collaborations, under the 'triple helix' context, investigating the relationships developed between different kinds of organizations and especially between private sector (large firms and SMEs) and public sector (universities, research centers, and public agencies). So, it is assumed that the profit oriented organizations (large firms and SMEs) consider actors embedded to academic and research context as pools of knowledge, so the latter are preferred for repeated collaborations compared to other kinds of organizations. This leads to the following hypothesis:

H2b: The case when a private actor (large firm or SME) collaborates with a university or research center (actors with organizational distance) affects positively the repeated collaborations between them.

Social proximity refers to the embeddedness of actors in the micro-level, in terms of friendship, kinship, and experience (Boschma, 2005). Social proximity can affect positively the trust between two actors, as trust fosters knowledge exchange (Maskell & Malmberg, 1999). According to Boschma (2005) social proximity is a strong predictor for the existence of a link between two actors, as actors due to uncertainty they turn for cooperation to actors which they know from the past, than creating anonymous newly established relations. However, too much social proximity can be harmful for the innovative performance as it can result to lock-in preventing new ideas from new cooperation to enter the knowledge network. The majority of the empirical literature tends to consider the idea of social proximity equivalent to the concept of strong ties (Granovetter, 1973). Several scholars measure social proximity in this way (Coenen et al, 2004; Oerlemans & Meeus, 2005; Breschi & Lissoni, 2009; Broekel, 2015). However, these two concepts cannot be considered synonymous as the social proximity under this point of view indicates the existence of a relationship between two agents, while the strength of the ties indicates the frequency or the intensity of this relationship. Alternatively, in the empirical literature the social proximity is treated as the possibility of two actors to be close socially after sharing a common situation back in time (Broekel & 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). In the present research social proximity is not treated, as the structure of the dataset in projects and the reported repeated collaborations imply that exists already a collaboration between the two actors for it to be repeated. Additionally, this study aims to treat the repeated collaborations as an attribute and measurement of the quality of the relationship between the agents, and not as one of their attributes.

Finally, institutional proximity is an aspect of proximity where the actors share common institutional and cultural attributes. That is why sometimes in the literature it is also referred to as cultural proximity (Gertler, 1995; Knoben & Oerlemans, 2006; Capello et al, 2009; Caragliu & Nijkamp, 2012). Comparing the two notions, however, the cultural proximity can be considered mostly a part of the institutional proximity. So, institutional proximity is the one that actors can enjoy in the macro-level. It can be expressed by either formal institutions, such as laws, or informal institutions, such as cultural norms, and affect the way in which actors coordinate their actions. Institutional proximity provides to the actors stable conditions for knowledge transfer (Boschma & Frenken, 2010). Institutions constitute 'glue' in the knowledge network promoting collective actions, as they reduce uncertainty and transaction costs. The notion of institutional proximity includes both the idea that actors share the same formal rules for their economic activity, as well as, the same cultural values. A common language, shared habits, a common law system and other elements, secure a basis for coordination and interactive learning (Maskell & Malmberg, 1999). According to Ponds et al (2007), geographical proximity can compensate for the absence of institutional proximity, while institutional proximity facilitates the interaction between actors located in distant places. So, in the present research the institutional proximity it is measured with the case that one actor is located in the region under investigation and the other to be located inside the borders of the country, sharing the same institutional and cultural context. Due to the fact that the present case study takes place in Italy, considering the normative, institutional, and cultural differences between the north and the south of the country, in a second level, the control about institutional proximity is realized considering the cases in which one actor is located in the region under investigation and the other in one of the regions of North Italy.

Another classification of proximity is the one of Caragliu and Nijkamp (2016). They divide the proximity in three types: geographical, cognitive, and relational. Although the authors define the first two kinds of proximity in the same way as Broekel and Boschma (2012), they differentiate by adding relational proximity. Relational proximity is the capability of regions to learn through cooperation. The actors that are proximate relationally take part into the collective learning process. The relational capital can be interpreted as a set of bilateral relationships developed by the local actors with other actors inside and outside the region, facilitating the interaction and knowledge transfer. The notion of relational proximity, however, was introduced in the literature quite earlier, but it is not treated under the point of view of a specific definition. Some of the first references in relational proximity were in combination with the spatial aspect (Storper & Venables, 2002; Gertler, 2003; Bathelt et al, 2004), binding the relational proximity with the notion of "being-there". Amin and Cohendet (2005) attempt to disconnect this notion from the face-to-face contacts, using the strength of the ties to measure it. In several cases it is measured by productive linkages (Giuliani, 2005), while the trade of the goods produced is implying transfer of information. Moodysson and Jonsson (2007) use the concept of relational proximity as an umbrella including the Boschma's (2005) non-tangible notions of proximity (cognitive, organizational, social and institutional), measured in terms of similarities apart from the geographical distance. Basile et al (2012) measure relational proximity in terms of similarities of regions, in the same way that Caragliu and Nijkamp (2016) do.

In this study, however, the relational proximity is treated in a different way but in more specific way than in all the above aspects. My approach of relational proximity is strictly embedded to the network element of which an economic actor is part. It is defined in terms of the position of the actor inside the regional knowledge network in respect with the rest of the actors. In other words, it is measured how central is the actor in the network and then compared with the centrality of other actors. In case that two actors are relationally close, this means that they have similarly central position in the network, while if they are relationally distant, the one is more central and the other more peripheral. This definition of relational proximity stems from the theory of preferential attachment, which supports that the most connected (central) nodes are more probable to receive new links (Barabasi & Albert, 1999). In other words, more peripheral actors when they enter in the knowledge network, in order to enter as well the knowledge transfer process, they prefer to interact with more central actors, while the more central actors prefer to exchange knowledge with other central actors. Additionally, actors can be relationally proximate or distant in more than one ways: for example in terms of number of interactions between them (degree centrality), connections with different networks as brokers (betweenness centrality), importance of connections (eigenvector centrality) etc. This thesis is the first attempt to control for the effect of relational proximity by the centrality of the actors, so only the centrality in terms of number of connections was used.

Getting deeper to the notion of preferential attachment (Barabasi & Albert, 1999) from which stems the present definition of relational proximity, the reasoning for the important effect of relational proximity is based on the idea that economic actors do not innovate in isolation (Doloreux & Parto, 2002). Since the actors become a part of the network, they increase their connectivity according to how much they are suitable to compete for connections (Bianconi & Barabasi, 2001; Abbasi et al, 2012). In this way, the fitter nodes overcome in this competition of ties the less fit ones. So, when a new actor enters into the social network, seeks to be connected with central well-established actors (Newman, 2001; Wagner & Leydesdorff, 2005; Capocci et al, 2006; Kumar et al, 2010). Hence, there is a cumulative advantage for the better positioned actors (Powell et al, 1996; Gulati, 1999; 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 (Glucker, 2007). In sum, in line with the literature of preferential attachment, the more peripheral actors (new entrants and less connected actors) seek to repeat collaborations with the actors that are better relationally positioned inside the knowledge network. This leads to the following hypothesis:

H3: The relational distance in terms of degree centrality of two actors affects positively the repeated collaborations between them.

Summing up, the present research deals with the notions of geographical, institutional and organizational proximities, and introduces the notion of relational proximity in an empirical network attempt. It does not control for the effect of the cognitive proximity as there are not sufficient data for the projects of national and regional spectrum, while the omission of these projects would result to the loss of important information on the knowledge creation and transfer inside the region. Also, as mentioned above the present research does not control for social proximity, as the aim of this study is to treat repeated interactions as an attribute that characterizes the intensity of the relationship between two actors and not as an attribute of a specific entity.

2.5 Dynamic Analysis of Knowledge Networks

For analyzing empirically the knowledge networks, literature used Social Network Analysis (SNA) as method. This method will be extensively analyzed in a later chapter about data and methodology (Chapter 4). There is a wide variety of topics in economics in which SNA is applied. However, only in the last decade networks were applied in the fields of economic geography and regional economics. According to Ter Wal and Boschma (2009), only recently, social network analysis techniques were introduced in order to describe how the structure of interactions in regions looks like. Thus, SNA can contribute further to the analysis of RIS (Cooke, 2001). This strand of literature argues that the case in which organizations in a region are not well connected can harm the innovation process. With the help of SNA the concept of RIS can be more systematically analyzed by mapping and studying in a quantitative way the relationships that regional key actors are developing inside and outside the region. In this way, it is revealed the connectivity of these key actors in spatial and temporal aspects. While the use of SNA to describe and analyze the relationships between individuals, firms, and institutions over space is widely adopted, it is less clear how to study the evolution of these connections over time.

The temporal point of view concerns how networks evolve and change over time (Ter Wal & Boschma, 2009; 2011). The majority of the existing empirical studies on networks adopt a static point of view, representing a network of an RIS at a certain point in time (Giuliani & Bell, 2005; Morrison, 2008). On the other hand, in the broader field of network theory, the interest shifted in the network dynamics, introducing concepts like preferential attachment. In network dynamics, preferential attachment plays an important role (Barabasi & Albert, 1999). Preferential attachment is a procedure of network expansion in which the probability of a new node entering the network to create a tie with a certain other node is proportional to the number of ties that this second node already has. So, according to the preferential attachment, the central actors of a network with its expansion remain central, and respectively the peripheral ones remain peripheral.

On knowledge networks, however, there must be also other drivers for the evolution of the network except from the preferential attachment. The attributes or the linkages that another actor has should be taken into consideration by a node before it decides to collaborate. Also, an existing actor should make the decision either to create a new tie and collaborate with a new actor in the network or to repeat an already existing collaboration. From what is this decision affected? Do factors of the environment of the actor play role to its collaboration and knowledge creation decisions? And consequently, how external events (positive or negative) affect the evolution of the network?

In the field of economic, knowledge and inter-organizational networks there is still a gap in the application of dynamic network analysis (Gluckler, 2007; Ter Wal & Boschma, 2009). There are recent attempts that studied economic or knowledge networks from a time perspective (Cantner & Graf, 2006; Broekel & Boschma, 2012; Balland et al, 2013; ter Wal, 2013; Giuliani, 2013). Cantner and Graf (2006), using the innovator networks in Jena (Germany), stress out the fact that success brings success; meaning that successful co-operations between researchers are repeated in a second time period.

Following this strand of research, the aim of the present work is to answer the aforementioned questions, introducing the time perspective in the knowledge network of an emerging ICT innovation system. Its main objective is to investigate the evolution of the ties in the regional network before and after an external negative event, line the global economic recession of 2007. So, the present research argues that in a period of crisis (2008-2014) the role of an actor inside the network in previous periods (2000-2007) is important for the inertia of the knowledge network. While facing a period of economic slowdown, trust (from previous co-operations) becomes more important. Actors inside the RIS are less willing to risk investing their efforts and money in knowledge transfer activities with actors they do not know. During periods of uncertainty and high risk, the actors in a knowledge network turn to the creation of strong ties with other actors they trust; the role that plays an actor inside the regional knowledge network in previous times creates this trust. Inside knowledge networks, different actors can play different roles considering the multiple relationships that indicate knowledge transfer (in this case collaboration, coordination, and funding) (see Chapter 4). This argument leads to the following hypothesis:

H4: In a period of high uncertainty (2008-2014) the effect of past co-operations on the occurrence of strong ties between actors is expected to be higher than in a period of low uncertainty (2000-2007)

Except from the preferential attachment (Barabasi & Albert, 1999), there should be also other drivers that affect the evolution of the knowledge network, like the common attributes between the actors. A key question in the literature is how to explain the reasons why actors in a knowledge network choose other actors in order to create or strengthen relationships. By the static point of view, empirical studies have indicated the important role of geographical proximity as determinant of networking (Giuliani & Bell, 2005; Ponds et al, 2007; Breschi & Lissoni, 2009; Balland, 2012; Balland et al, 2013; D'Este et al, 2013). In the same time, other studies investigated the role of the non-geographical dimensions of proximity and the effect of their presence or absence in innovation or knowledge networks (Boschma & Frenken, 2010; Broekel & Boschma, 2012; Cassi & Plunket, 2013).

However, the recent studies are focused on how the proximity dimensions affect the evolution in time of the knowledge network (Broekel & Boschma, 2012; Balland et al, 2013; ter Wal, 2013; Giuliani, 2013). On the other hand, Balland et al (2014) argue that this effect can be traced vice versa; that repeated collaborations may result to more proximate actors. However, as it is also perceived in the present work, the attributes of the actors are slower to change than the collaborative relationships between them, demonstrating a degree of inertia (Padgett & Powell, 2012). Thus, the present research takes into consideration the influence of proximity changes over time, adopting a dynamic approach. In this strand of literature, Broekel and Boschma (2012) tested the proximity paradox with data from the Dutch aviation industry. This supports that proximity is necessary for connecting knowledge networks, while it does not implies superior innovative performance. Balland et al (2013) have explored how network evolution of global videogame industry is affected by proximity, actor characteristics and network structure. The authors argue that the geographical proximity has an important effect on the relationship formation through time, for the increasing technological complexity of this technological field. While Ter Wal (2013) argues in inventor network dynamics in German biotechnology industry about the fact that the geographical proximity as a criterion for choosing partners can be substituted by the prior collaboration with the same partners. So, the geographical proximity became less important because of the increasing codification of knowledge in this technological field. In the end, Giuliani (2013) supports as well that geographical proximity supports the repeated collaboration of actors in the Chile wine cluster.

Taking into consideration the literature that combines the evolution of knowledge and innovation networks, the present research introduces multiple factors, like the different kinds of relationships indicating knowledge transfer and several kinds of proximity, for understanding their role in the evolution of network during high-uncertainty periods. For exploring the dynamics of the knowledge network, I control and discuss the effect of three dimensions of proximity: geographical, institutional, and organizational proximities. Hence, the corresponding question is whether the attributes of actors play a more important role to the evolution of the regional knowledge network after an external negative event. From the literature discussed above, I assume that during a period of crisis, proximity is expected to matter more because it is associated to lower costs of transaction and lower risk in new collaborations. So, the following hypothesis is formed:

H5: In a period of high uncertainty (2008-2014) the effect of proximity on the occurrence of strong ties between actors is expected to be higher than in a period of low uncertainty (2000-2007)

Summing up, the dynamics of knowledge networks are still far from being explored, though. There are gaps in the literature in studying in a more profound way the presence or absence of different kinds of proximity and their effect in the network evolution. Also, the importance of the position of actors inside the network and its influence to the network development is another issue remaining to be explored. Finally, the most important is the introduction to the time aspect of important external negative events to the RIS and the way that these events affect the evolution of network. These are issues that the present research intends to explore, and its main contribution to the body of literature of network dynamics inside emerging RIS.

CHAPTER 3

ABOUT THIS RESEARCH

The success of RIS today depends on their ability to embody all kinds of talent, knowledge and capabilities that are needed to deliver high value to customers at local, national and international levels (Assimakopoulos et al, 2015). Due to the technological advances, the interest of regional, national and supra-national institutions is concentrated on RIS specialized in R&D and knowledge production on Information and Communication Technologies (ICT). According to OECD (2003), ICT goods are those that “are either intended to fulfill the function of information processing and communication by electronic means, including transmission and display, or which use electronic processing to detect, measure and/or record physical phenomena, or to control a physical process”. ICT products are particular, as they involve high-technology. Concepts, methods and applications involved in ICT are constantly evolving. However, as ICT products are high technological and their production is knowledge intensive, regions that produce them have to develop networks of knowledge flows, in order to bring together expertise and resources.

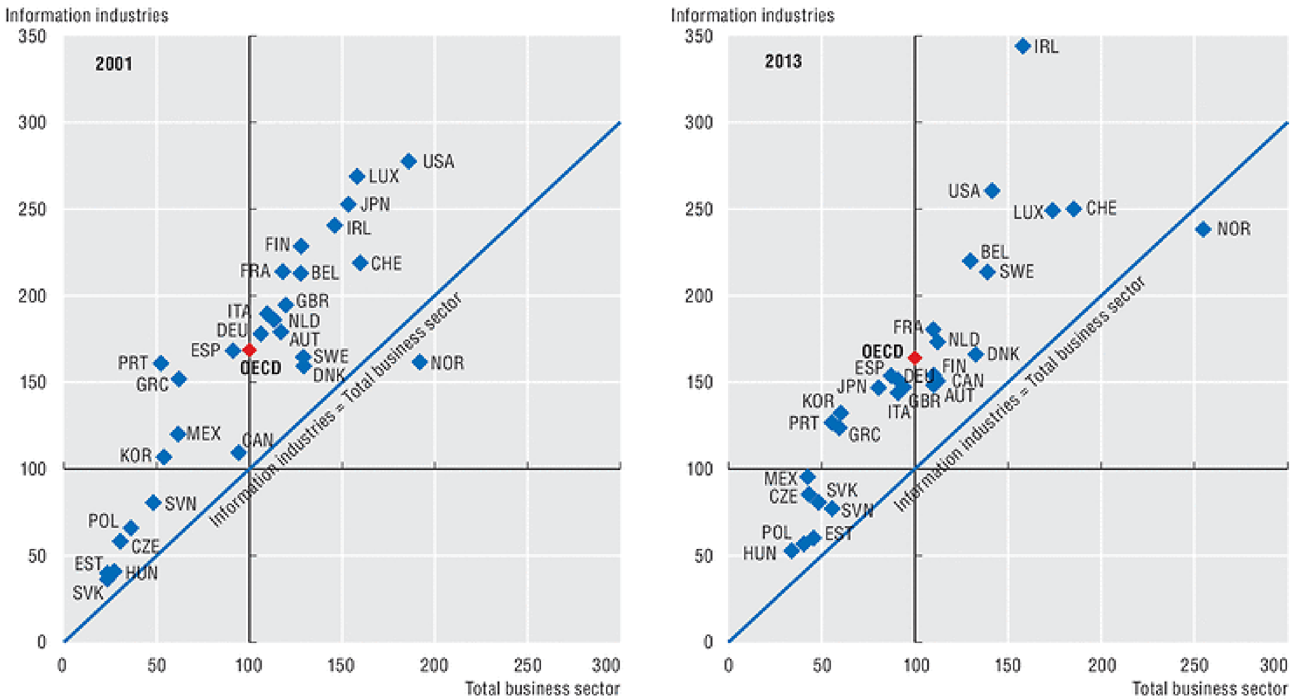

Figure 5: Labor productivity in information industries, 2001 and 2013 (OECD, 2015)

Recently, a new generation of ICT appeared, like the Internet of Things, big data, and so on, and a series of inventions and applications in material and health. In the years 2010-2012, the leading countries in research of this new generation of ICT are United States, Japan and South Korea, with European countries to follow (Germany and France) (OECD, 2015). As presented in Figure 5, labor productivity and consequently industrial growth in Italy has been reduced in the time span between 2001 and 2013, for the field of information industries (OECD, 2015).

This chapter is focused on the understanding of the environment within which the innovation process takes place in the Italian region of Trentino, as this specific region of Italy presents a rise in the ICT activity despite the general reduction for the rest of Italian regions after the burst of economic crisis of 2007. In the second part of this chapter the goals of this research are presented. The gaps in the literature are defined and presented, while the research questions and hypotheses that answer them aim to fill these gaps.

3.1 What is so special about Trentino?

The present research analyzes 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 60's and 70's. Although agriculture has still strategic importance for the provincial economy, the last fifteen years Trentino had an impressive growth in the number of businesses on 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. Considering its funding policy, it manages the 9/10 of the taxes collected in its territory. So, the province of Trento the last two decades has decided to invest heavily on ICT sector, for making Trentino a key technology hub in Central Europe. Although the size of this RIS is relatively small compared to other innovation systems of established clusters in Europe, it allows the study of the entire ICT innovation system since its birth.

In Figure 6 below, the GDP (Gross Domestic Product) in current market prices (Eurostat, 2016) for Italy and Trentino is plotted respectively, for the years from 2000 to 2014. It is obvious that this specific region of Italy was affected by the economic crisis, as happened to the rest of

Italian regions in the end of 2007. There is a reduction to the GDP also in Trentino; however, it is still higher by the average GDP of the rest of Italy.

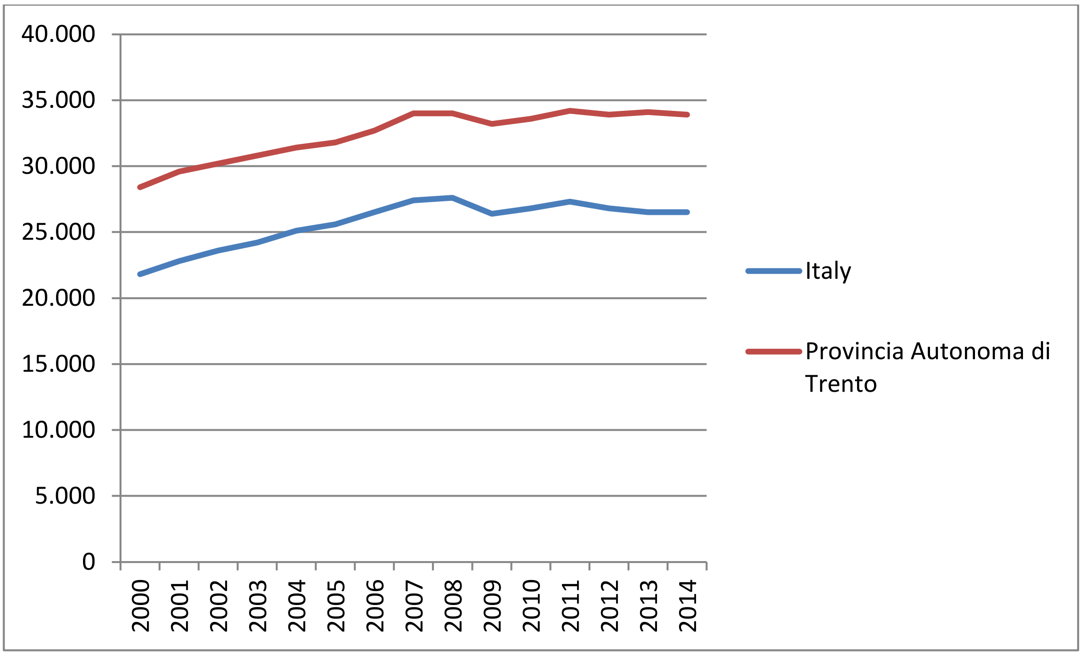

Figure 6: Gross Domestic Product in current market prices by NUTS 2 regions (Eurostat, 2016)

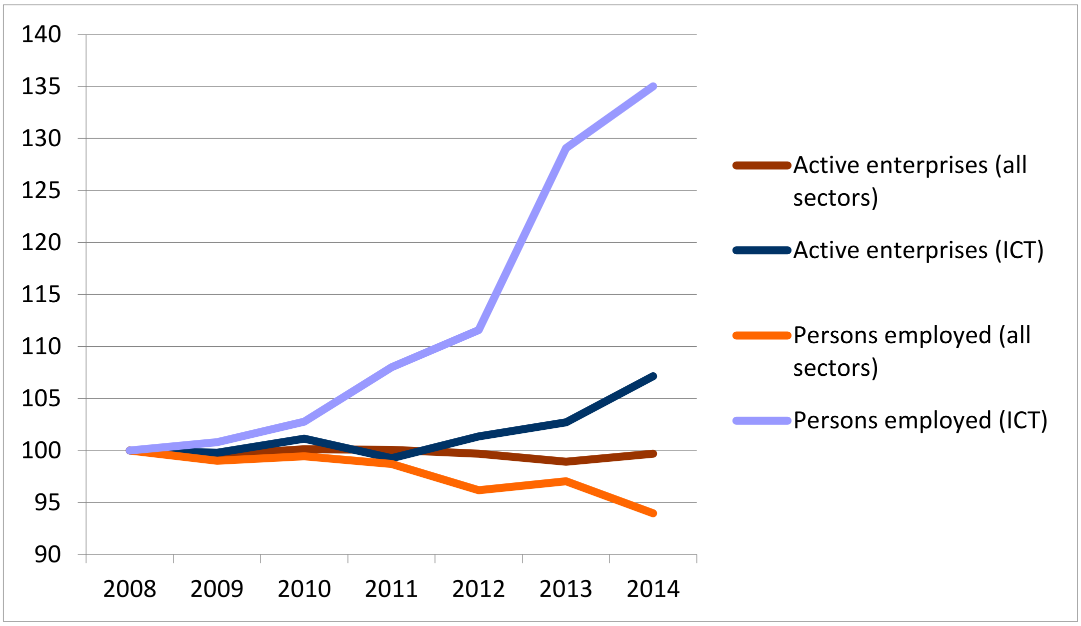

Figure 7: Number of active enterprises and people employed in the Trentino economy and ICT sector (2008-2014)

Figure 7 shows the number of the active enterprises and employees in the entire economy of Trentino and in the ICT sector separately, for the period that follows the burst of economic crisis starting from 2008 (Eurostat, 2016). In the crisis period the overall number of active enterprises shrinks in Trentino, as the number of people. The opposite holds for the ICT sector, which appears to be more resilient: both the number of active enterprises and employment grew in the crisis. It has to be noted that this trend is not at all common to the rest of the country. Between 2011 and 2014 (data on previous years are not available for Italy) the number of people employed in ICT reduced of about 2 percent, one half of the reduction registered in all the other sectors.

3.2 Trentino through Time: A short economic history

Due to the soft industrialization, which Trentino experienced in the decades of 1960s and 1970s and mentioned in the previous section of this thesis, industrial policies were introduced having as main objective to support development and employment in the declining areas by attracting industrial investments capable of upgrading the competitiveness of the province for competing with other industrialized European regions. Development issues were associated to the attracting of capital considered the key factor for facing employment issues. During the 1980s the interest shifted from attracting large firms to attracting small firms within the knowledge economy. Simultaneously, the province of Trentino designed strategies seeking to attract institutional subjects in order to promote international research and for first time there was a distinction between industrial and innovation policy. The authorities in this way were seeking to maintain the employment levels in the region. So, in 1980s the development of small companies with focus to a single type of industry started. Hence during 1990s the investments in the ICT sector increased, based on the US model. In the same time, the public agencies also introduced ICT in its general form in order to be established as players in the region.

As Proto et al (2012) in their OECD report and the data of the present work confirm, the last decade is characterized by the reordering of research activities in the region, the birth of the Trentino Technological Cluster and the transfer of the University under provincial administration. This phase is very important for the development of the knowledge and the knowledge networks within the region. During 2000s the industrial, innovation and research policies start to converge. The Province launch projects in order to foster the innovation process in which the knowledge networks play a key role, ensuring the continuity of the research and innovation activities carried out until that moment, enhancing the agglomeration processes having in mind the available regional resources, extending the experience acquired by the Trentino Technological District on energy and environment to other sectors of the Trentino economy, and specializing Trentino Sviluppo (the local development body) in order to become a key player in the local innovation process (Law 14/05)

The main element of the above law is the capacity of the RIS to identify the needs of the region in knowledge, research and innovation, and design solutions and strategies. So, in this way the role of the RIS integrator was attributed to the PAT, constituting it capable of indicating to the research and other sectors the paths and directions that can be shared by all the local actors. Regarding the knowledge networks, the composite character of the RIS is emphasized, including many actors which in the same time collaborate and compete with each other. In terms of provincial funding, the Province introduced possibilities of receiving funding for a research chain by the Law 6/99 and its transformations in 2006.

In 2006, the Provincial government used the instruments identified earlier to review the RIS. So, that was the year in which the review of public bodies took place. Fondazione Bruno Kessler replaced the Istituto Trentino di Cultura which was abolished in the beginning of 2007. Early in 2008, Fondazione Edmund Mach replaced the Istituto Agrario San Michele and the Centro di Ecologia Alpina. At the end of 2006, the Multiannual Research Programme of 2006-2008 was also approved. This program emphasized on the thematic areas considered to be a priority, the general strategies of intervention and implementation of policies, and the increase of public funding activating the Single Research Fund. The same year the Provincial Development Plan set a number of objectives for the RIS: A greater internationalization of the research system, an increase of the percentage of non-provincial public and private funding, the definition and implementation of a research assessment system, the promotion of synergies between research and local development policies in order to attract large firms (e.g. the Microsoft Research Center).

On 2010, the new Provincial Development Program allocated 84 million euro in research activities and policies, only for the current year. This program is based on the concept of territorial capital and has as objective to strengthen the network. It priorities were the definition of an arrangement for cooperation among the PAT, the university, and the Edmund Mach and Bruno Kessler Foundations in order to coordinate the research at the provincial level, attaining results of international importance and establishing collaborations between different bodies of the region and of the Euroregion (Trentino-Alto Adige-South Tyrol). Its further objectives were to qualify public investments in research and strengthen the collaborations with the private sector, to promote the creation of an ICT cluster in the region for promoting the efficient collaborations between academia/research, public sector, and private firms, to consolidate the Trentino Technological District promoting a system of alliances and collaborations including the PAT, to review the financial incentives and prefer the initiatives that enhance the innovation, the creation of business networks, size consolidation, the creation of new enterprises and internationalization, and to enhance the entrepreneurships and the creation of new enterprises stemming from the research activity (spin-offs).

According to the Development Program, it was the rather the public sector that drives the R&D in Trentino. In 2006, the public share of R&D in Trentino was 69.8% compared to its level in Italy (47.5%) and in Europe (34.8%) (Proto et al, 2012). The Trentino provincial funding for research has increased since 2000. The Province doing so had as objectives to identify research and higher education areas where outcomes of international relevance could be obtained, to internationalize both researchers and academics in order to increase the attraction on the most important scientific markets and to construct a network of collaborations with the best examples of national and international research, to develop a network of collaborations for the promotion of research in Euroregion involving both academic institutions and business sector, to support the entrepreneurial and production in Trentino, while interpreting the innovative processes and focusing into the finalization of research, and finally, to supply indications and instruments which are needed for building a society capable to be close to the needs of citizens.

The knowledge network keeps on being central in the design of research and innovation policies in Trentino region, despite the burst of the economic crisis. The difficulties resulting from the economic slowdown have helped to increase the awareness of the importance of creating networks between the local actors.

3.3 The Institutional Setting of Trentino

The network of operators who interact with the research system in Trentino varies from sector to sector. For example in ICT, the relations with local firms have structured and developed over the years, while in others, like hydraulic engineering, the main partners for research are the public agencies and engineering companies. In this section are presented the main players in Trentino region in the knowledge production and transfer, as they were presented by Proto et al (2012) in their paper for OECD.

The University of Trento is at the top of the national classification for several research and academic parameters. The University of Trento was founded in 1960s and its first department was Sociology to train the employees of the local public administration. In the later years the engineering department was created to meet the needs of the local businesses. Since then, the rest of the departments were created giving to the university its present form. Patent research is a recent topic of interest for the university. Today the university has over twenty active patents, spin-offs and start-ups, whose number is increasing. The university is also active in knowledge transfer as it builds strategic partnerships with the universities inside the Euroregion, Italy and the rest of the world.

The research network in Trentino is distinguished by the presence of two main Foundations, besides the University, and several public research centers. These foundations were public research institutions of the Autonomous Province of Trento (PAT) until 2005, although still the PAT continues to provide them with over 60% of funding. The Fondazione Bruno Kessler (FBK) was set up in 2007, formerly Istituto Trentino di Cultura, began its operations in the science and technology field since the late 1980s. However, it did not have structured technology transfer activities. With its change to Foundation, it gave greater emphasis on the knowledge transfer and its connectivity with the local actors. Until now it produced licenses, patents, new business incubation, spin-off etc. The main characteristic of the activity of FBK is to keep up with world-class standards in research and the increasing attention to the local issues. The other foundation of the region is the Fondazione Edmund Mach (FEM), which was created in 2008 out of the former Istituto S.Michele. It is part of the strategy of the local government for supporting agriculture and innovative applications in this field in local, national and international levels.

The RIS in Trentino, besides the university and the two main foundations, includes an important series of other research centers that play a crucial role in the knowledge network in Trentino:

- the Center for the Physics of Aggregated States (CeFSA) which is part of the Institute for Photonics and Nanotechnology with branches in Rome, Milan and Trento;
- the Microsoft Research – University of Trento Center of Computational and System Biology (Cosbi), which is the scientific partnership between the two institutions and co-funded by the PAT, intending to understand the systemic biological processes with the help of the most recent technological developments in computer science;
- the Create-Net is a non-profit organization founded by the University of Trento and the FBK for achieving excellence in telecommunications, while it is particularly active in European projects and in the local knowledge network;

- the European Center of Theoretical Studies in Nuclear Physics, which is a European research institute founded in 1993, conducting scientific research with the European Science Foundation, pursuing scientific excellence at the international level;
- the European Research Institute on Cooperative and Social Enterprises (Euricse), which is an institute that includes the University of Trento, the PAT and other partners who operate as public or private cooperatives in the field of scientific research;
- the OECD LEED Center for Local Development, which is an integral part of the OECD (Organization for Economic Cooperation and Development) and its mission is to develop capabilities in the national and local administrations of the OECD member and non-member states;
- the CNR-ISTC which is a national laboratory that uses an interdisciplinary approach ranging from cognitive sciences to IT, artificial intelligence, linguistics, philosophy and logic and offers applications focused on biomedicine, company process management, legal issues, IT security and semantic web;
- the Institute for Industrial Technologies and Automation (CNR-ITIA), founded by the PAT and the National Research Council (CNR), carries out R&D in manufacturing technology using mechatronics;
- the CNR-IVALSA is the institute of the National Research Council for the promotion of timber and arboreal species and works on studies that range from biomass to construction science to diagnostics;
- the Trentino Technological Cluster for Energy and Environment (Habitech) promotes the harmonization and the integration of the LEED and CNR certifications.

One of the key players in the knowledge network of Trentino is the Autonomous Province of Trento (PAT) itself. The strategic objective of the PAT is to increase the size of local firms. The administration tries to stimulate their growth by developing company networks. Also, the PAT co-funds firm initiatives and applies policies that guarantee financing to private local firms and clusters. PAT has a series of executional bodies that promote research in scientific fields and knowledge transfer.

Trentino Sviluppo is such a local development agency within the PAT constituting its main knowledge transfer agency. The main objective of Trentino Sviluppo is to facilitate the creation of partnerships, while at the academic level it can be a useful process facilitator in network development. Additionally, Trentino Sviluppo manages business incubation in the region by its Business Information Centers.

Informatica Trentina is also part of the PAT and it is the main organizer of firm networks and relations in the ICT sector. It is the in-house agency for public and business services, besides Trentino Network, which works with networks and technology. The thirty percent of the resources that Informatica Trentina receives from PAT is transferred to the local firms.

Last but not least, an important element of the knowledge network of Trentino is the private firms. The private firms in Trentino do not have the strong tradition found in other Italian regions of developing strategies based on firm networks. This has improved during the past decade due to the initiatives and support policies of the PAT. The public sector provides fundamental funding to promote the creation and development of network activities. During the last years, links between firms and the field of research were developed in specific sectors, like ICT, however, there is still long way to go. The last efforts of the local government are focused to maintenance of the potential of the internal knowledge network, while connecting it with national and foreign markets and networks.

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CHAPTER 4

DATA AND METHODOLOGY

In order to find an answer to the research questions (Chapter 3) derived from the gaps in the literature, the discussion of the data collection and its analysis for the case of Trentino is essential for grasping the organizational and technological context in which the knowledge creation that fosters innovation takes place in the RIS. This research deploys a comprehensive mapping of all ICT actors in the region of Trentino and their collaboration networks in the ecosystem through Social Network Analysis (SNA) and visualization (Wasserman & Faust, 1994).

This chapter is divided in three parts in order to cover both the data collection procedure and the methodologies employed for the completion of the present research. The first part describes the main method of analysis and visualization used in the present research; Social Network Analysis. SNA is used for describing the network of knowledge in Trentino in terms of actor attributes and the relationships that these actors develop between them. The second part describes thoroughly the kind and structure of the data gathered, as well as the way in which this dataset was put together. The third and last part describes the particular method of network regression used to make conclusions about the strength of the ties between the network actors; this method is called Quadratic Assignment Procedure (QAP).

4.1 Social Network Analysis (SNA)

In order to analyze knowledge intensive RIS, the recent literature introduced social network analysis techniques (Ter Wal & Boschma, 2009) that constitutes a powerful tool for making conclusions about the evolution of RIS (Cooke, 2001).

Social Network Analysis (SNA) is the method of analyzing social structures using network and graph theory. It represents these social structures in terms of nodes (individuals, firms, events) and ties (relationships, interactions) between them. There is a wide variety of topics in economics in which SNA is performed. One of the emerging fields in which SNA is employed is innovation and knowledge economics, as the knowledge transfer that stimulates innovation procedure can be considered as social structure, where actors (individuals or organizations) interact in several ways. In all the cases the data availability is the main concern as the usual sampling methods of firms are not appropriate for SNA applications. In order to perform SNA the entire set of actors involved is needed since a sampling could cause omissions of important actors or disconnect parts of the network, that in reality are connected. This is significant in the representation of knowledge and innovation networks as omitted parts of network can give interrupted knowledge flows, which may lead to false conclusions. The only selection that can happen at the relationship level, as not all kinds of relationships can be measurable or able to be investigated. For example, unofficial relationships like friendship or advice seeking are difficult to be traced.

However, the application of SNA techniques in economic studies is far from being exploited, despite the increasing amount of empirical research in the field. The data collected for studies that apply SNA methodology can be either primary or secondary. Although several ways to collect primary network data exist, the main two ones, widely used in the literature of social sciences, are the "snowball" sampling technique and the "roster-recall" methodology (Morrison, 2008; Boschma & Ter Wal, 2007). For the collection of secondary network data, there are different sources of them that are exploited by the international literature. The most common sources, however, are the patent data (Jaffe et al, 1993; Breschi & Lissoni, 2003; Balconi et al, 2004; Cantner & Graf, 2006), co-authorships (Ponds et al, 2007), and collaboration in R&D projects (Maggioni, 2002; Owen-Smith et al, 2002).

The snowball sampling is a non-probability sampling technique in which actors existing in the study indicate future participants in it among their acquaintances. This method uses a small number of initial participants which they select through their social network the next participants, according to the question posed by the research. This second group of participants indicates other participants and so on. Thus, the term "snowball" is justified, describing the proportion of the snowball increasing its size as it roll downhill (Carrington et al, 2005). This method is mostly used in sociology, in order to locate hidden populations, as it has certain drawbacks that constitute it inappropriate for network research in RIS. The main disadvantages of this method are i) the community bias, as the first participants will strongly affect the sample, ii) the fact that it is not random, so the size of the population is unknown, and iii) the non-identification of isolates in the network when they exist.

In a number of studies on networks in RIS (Morrison, 2008; Giuliani & Bell, 2005; Boschma & Ter Wall, 2007), primary data were collected by the so-called "roster-recall" methodology. This method of interviews collects network data of a predefined population of actors.

As first step, the researchers construct a roster including the entire list of the predefined actors, which may fulfill the criteria of the relationship investigated. The participants have to indicate the actors of this list with which they have the relationship under research. Then the participants have to recall all the other actors with which they had this type of relationship. This method results in a complete network, as long as all the predefined actors take part in the survey. The roster-recall method has two main advantages: first, it is a statistically robust method, especially when different relationships of the same actors are compared, and second, through the survey further information on some special characteristics of the relationships formed between actors can be collected. However, it has also four main shortcomings. In this method the complete data should be available, which means that all relationships of all actors should be included in the network. So, a high response rate is needed. It is also time-intensive, because of the interviews conducted. Moreover, the type of relationship that will be indicated by the participant depends on the formulation of the question of the researcher. Finally, this method produces static networks, as in time research is not feasible (Ter Wall & Boschma, 2009). An alternative technique is the so-called free-recall method, where the participants have to recall the actors with which they have the predefined kind of relationship (Cantner et al, 2015; Giuliani & Pietrobelli, 2011). In this way, they can expand the network beyond the local actors and identifying the most important of them, although they may lose a part of the network.

In order to overcome the limitations of primary data collection, the majority of network studies in regional economics and economic geography use secondary datasets. These datasets can include one or more relationships among actors that can be found in co-patenting, co-authorship and citations, or common participation in R&D projects. Especially in the field of knowledge generation and transfer these are relationships that can indicate a knowledge flow from one actor to another. All the aforementioned methods result in complete networks, when the data is available. This depends on the relationships which the researcher wants to study, the unit of analysis that constitutes the actors in the network study, and the policy on data privacy of every region, country, or institutional structure.

The most commonly used source of secondary data is the co-patenting (Jaffe et al, 1993; Breschi & Lissoni, 2003; Balconi et al, 2004; Cantner & Graf, 2006). The patents are treated as relational data, forming networks of inventors or institutions in which inventors are based. Patent data are easy to retrieve and may give information on specialized labor mobility in space or sector (Ter Wal & Boschma, 2009). However, as mentioned earlier in this chapter the main shortcoming of patent data is that not all sectors are patenting. In high-technological fast-changing sectors and especially on ICT one, the majority of novelties is not patented, which constitutes the use of patent data for detecting knowledge transfer not sufficient (Cantner & Graf, 2006).

Another source of secondary network data is the co-authorship in scientific papers (Ponds et al, 2007). The co-authorship data of scientific publications constitutes the most common output of scientific research. In the network occurring, the actors can be either individuals or organizations, which can be traced by the affiliation addresses of the authors. This method, however, highly depends on the choice of the unit of analysis. For instance, it is questionable how to treat cases like an individual with two affiliations or a multi-authored paper with one affiliation.

The last kind of network secondary data discussed is the common participation in R&D projects (Maggioni, 2002; Owen-Smith et al, 2002). The R&D collaboration data consists of the actors participating in the project, and thus circulating knowledge among them. These actors are organizations and institutions. Every two actors that collaborate in an R&D project are connected between them. Data on R&D projects can include other types of relation than the collaboration, like cooperating or funding actors, as well as several attributes of the participating actors can be traced and studied. So, this kind of data can result to a multilevel network, where different kinds of relationships can be traced and measured. The main drawback of this data source is that it is difficult to be retrieved, depending on policy of the regions on data privacy. However, when they are obtained they result to a complete network of knowledge transfer.

4.2 Description of the Data

The Information and Communication Technologies (ICT) sector constitutes a knowledge intensive sector, involving high technological products with constantly evolving methods and applications. Thus, an RIS for the production of innovation in this kind of products has to develop networks of knowledge in order to bring together expertise and resources

As mentioned in the previous section, the most usual way to trace knowledge transfer for innovation is the co-inventing or co-patenting. A big majority of the existing studies use patent data to study knowledge and innovation networks (Balconi et al, 2004; Cantner & Graf, 2006). This is because this kind of data is usually complete and easy to retrieve. However, the use of patent data can be tricky as not all innovations are patented. Especially in the ICT field, a small percentage of novelties are patented and the quality of these patents is difficult to be measured. These facts make the use of patent data quite problematic. An alternative way to represent knowledge flows is the data from R&D cooperation. Owen-Smith et al (2002) have created networks of United States and Europe R&D cooperation. In this case, innovation and knowledge transfer is measured with project data. Opposite to the traditional statistics, where the main question is "in how many collaborative research projects do you participate?", when applying SNA methodology, like in this study, the question transforms to "with whom do you collaborate in research projects?"

Collaborative projects provide information at the organization level. Every two actors that collaborate in an R&D project are connected between them. Data on R&D projects can include other types of relation than the collaboration, like cooperating or funding actors, as well as several attributes of the participating actors can be traced and studied. So, this kind of data can result to a multilevel network, where different kinds of relationships can be traced and measured. As said before, the main drawback of this data source is that it is difficult to be retrieved, depending to policy of the regions on data privacy. However, when they are obtained they result to a complete network of knowledge transfer. Conducting a search in internet for every actor, I was able to add more attributes to the actors, like whether they are public or private or under which organizational context they operate. The structure of project data allows the tracing of knowledge creation and transfer through the different kinds of relationships developed between actors with different attributes. An example of the dataset produced by project is given in Table 2 below.

Table 2: Example of the dataset produced by collaborative projects

Project	**Duration of the Project**	**Funding Scheme**	**Coordinator of the Project**	**List of Participants**	**Attributes of Participants**
Name of the project (usually includes a full name and an acronym)	Start and End date of the project	Funding entity or entities (includes attributes like location)	Coordinating actor (includes attributes like location)	Name of Participant 01	Attribute of Participant 01
				Name of Participant 02	Attribute of Participant 02
				Name of Participant 03	Attribute of Participant 03

The present study uses data on collaborative projects on ICT that include at least one actor located in the region of Trentino, Italy. They are primary data collected by myself, however they constitute the complete dataset of collaborative projects on ICT for the region of Trentino, including the entire population of actors participated in the last fifteen years. The collection of this primary dataset didn't follow the procedures described above, but it was realized in three stages. In the first stage I downloaded from the website of Informatica Trentina S.p.A. the catalogue of actors that are involved in ICT activity. Informatica Trentina S.p.A. constitutes the instrument of the Autonomous

Province of Trento to provide global solutions in the field of ICT. The public or private institutions and research centers of the region that are involved in the innovation procedure on the field of ICT were included in the report of OPENLOC project (Proto et al, 2012). In the second stage I visited the official web pages of all the aforementioned organizations and institutions collecting the collaborative project data from their catalogues of project participation. In cases that the full data were not located in the official web page of the actor, I was visiting the official web page of the project in order to construct a database with the structure of entries presented above. The third and final stage of data collection was controlling for missing actors by filtering the web catalogues of research projects of European Commission (CORDIS), the catalogue of research projects of the Autonomous Province of Trento, and the rest of the smaller funders traced in the previous two stages. In this way, I was able to include the complete universe of actors that participated in ICT collaborative projects for the RIS of Trentino.

The collaborative projects used for the present thesis are, as mentioned above, all the collaborative projects on ICT that include at least one actor located in Trentino. According to their source of funding, these projects can be categorized in five kinds: the European funded, the nationally funded, the provincial funded, projects funded by the private sector, and other public entities funded projects. The European funded projects constitute the main bulk of the collaborative projects under research. Most of the European Commission funded collaborative projects must include at least three organizations from different European Union member states or associated countries. In addition of these three entities, any organization from anywhere in the world can be included in the consortium. The different calls for proposals announced by European Commission have different requirements according to the target of the program they are launching, i.e. there are actions targeting in SMEs. On the other hand, the national funded collaborative projects by the Italian government are powered mostly by the Italian Ministry of Education, University and Research. The procedure of partner selection for these projects is done according to the subject of the calls from the ministry and the thematic areas offered. They are targeting mostly to Italian actors, and although coordinated by Italian entities, the calls for collaborative projects address as well to international partners. The collaborative projects powered by PAT are targeting to the inclusion of the local actors to the knowledge creation and innovation process. The calls and programs for collaborative projects of the PAT address mainly to the local less connected actors, and they are coordinated locally, but there are cases in which national or international partners are asked to collaborate with the local entities. The private sector funded projects are projects oriented to the applied research and vary in their procedures for selecting partners according to the objectives of the funding entity. Finally, collaborative projects funded by other public entities have specific purposes and significantly differ from each other in terms of selection procedures. As the diversity in the requirements of every category of projects in order an actor to participate is big, in the present research all the collaborative projects are treated in the same way, assuming that all the actors collaborate with the same intensity, and controlling this collaborative relationship by introducing the coordination and funding relationships network.

The data period covered is from 2000 up to the end of 2014. Although there were pre-existing collaborative projects by some actors, 2000 was the year in which the PAT decided to start investing intensively on ICT research in order to lead the local economy towards high-technologies. Altogether, 2394 actors were identified, participating in 543 ICT collaborative projects. From these actors, the 6.55 percent (157 actors) is located in Trentino, the 15.29 percent (366 actors) is located in other regions of Italy and the rest 78.15 percent (1871 actors, the biggest volume of the actors) is located in other countries (Figure 8).

Another diversification is the one by organizational kind. In the present research there is a detailed distinction of the actors in terms of incentives and orientation of the organization. The actors are distinguished in universities, research centers, large firms, SMEs, public agencies and other kinds of organizations. Universities and research centers are organizations, whose main orientation is to generate and transfer knowledge through teaching and research activities. The contribution of these organizations to the innovation process nowadays, however, appears more significant as they are involved into synergies with organizations of different kinds in order to get access to funds or knowledge resources (Etzkowitz & Leydesdorff, 1995; Lawton Smith & Leydesdorff, 2014). In this work, the actors belonging to these two kinds of organizations are treated both separately and as a group, according to their organizational incentives. The industry sector is represented by organizationally profit oriented entities of different sizes. In the present work they are divided in large firms and SMEs. Small and medium sized enterprises (SMEs) are defined by European Commission (2003) as those with staff headcount less than 250 employees. Large firms are considered the firms with staff headcount more than 250 employees. The multinational enterprises are considered by the organizational point of view as one entity, while by the aspect of geographical proximity their branches are characterized differently if they are inside Trentino or Italy. In the category public agencies are included bodies that belong both to the local government and the wider Italian public, while in the partition of "Other" are included other organizational forms like NGO's. So, the 20.12 percent (481 actors) of the actors is universities, the 23.16 percent (555 actors) is research centers, the 19.57 percent (468 actors) is large firms, the

25.08 percent (601 actors) is SMEs, the 7.26 percent (174 actors) is public agencies, and the rest 4.8 percent (115 actors) is other kinds of organizations (Figure 9).

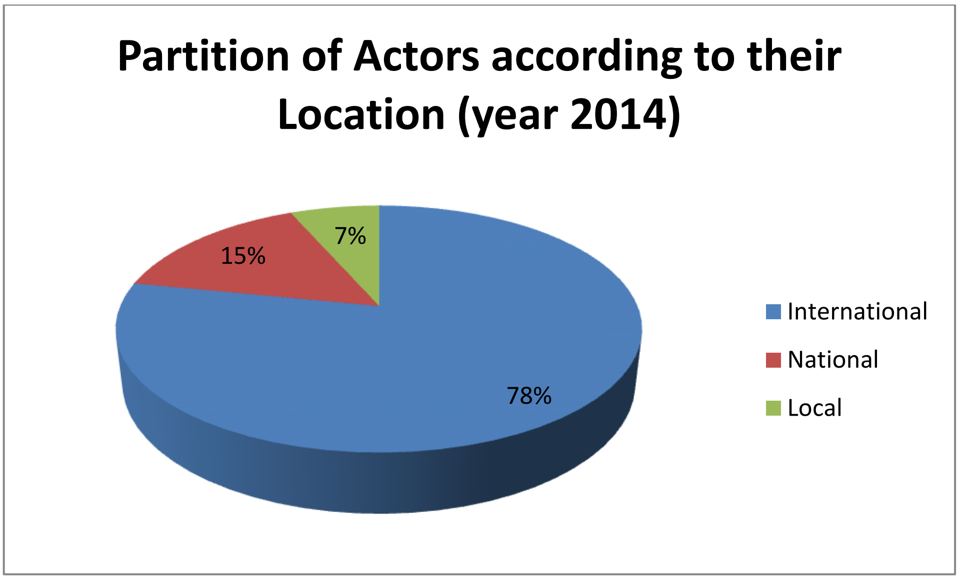

Figure 8: Partition of the actor of Trentino ICT innovation system according to their location

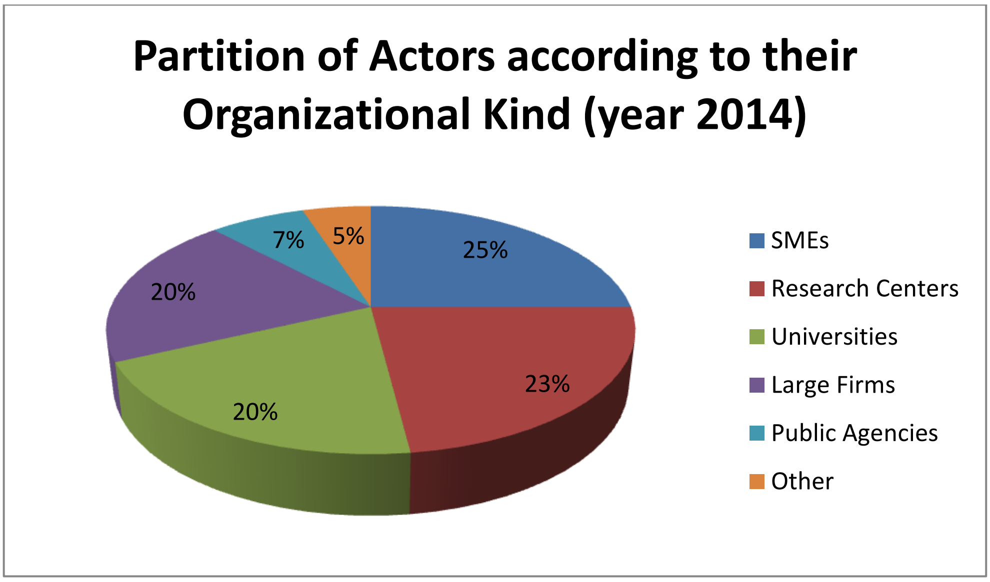

Figure 9: Partition of the actors of Trentino ICT innovation system according to their organizational kind

4.3 Estimation Models

The importance of network structures for knowledge transfer was emphasized by the literature in the field of regional economics. As these knowledge network structures foster innovation and consequently the economic growth in the regional context, it is important to explain the dynamics of this networks and how they evolve over time facilitating the knowledge generation and transfer. The dependent variables of the models discussed in the following chapters (see Chapters 6 and 7) are count variables. In statistics count variables are a type of data in which the observations take only positive integer values, and where these integers result from counting rather than ranking. In the present work the dependent variables are the number of ties in collaborative projects which every pair of actors has. In conventional econometrics, this type of data can be treated by Poisson models for count data. Poisson is a maximum likelihood estimator. The estimating equation cannot be written as a predictor function plus the standard error. So, it is not possible to examine how the standard errors relate across cases (cells) of the data matrix. Alternatively, something comparable could be the direct modeling of the interaction in terms of row (initiating actor) and column (receiving actor) identifiers. This would be a two-way fixed effects estimator. However, this would generate a large number of parameters in a dataset (like the present) that includes a big number of actors.

Consequently, the analysis of the relational dependent variables occurring by the networks requires specific statistical procedures. In this section the four main statistical procedures used in the literature are presented, while the one used by the present research for the analysis of the data, is discussed more extensively. According to Broekel et al (2014), the four main types of empirical strategy found in the literature are the gravity models (GM), the exponential random graph models (ERGM), the stochastic actor-oriented models (SAOM), and the quadratic assignment procedure (QAP). The last of these is used to analyze empirically the data of the present study.

GMs are used in social sciences to describe and predict behaviors that are assumed to imitate the Newton’s law of universal gravitation. The GM is not only a statistical method but also a conceptual model. As the social science models include objects with mass or distance, the elementary form of the GM predicts that the flow intensity between two objects or actors is correlated with the masses of the objects and inverse correlated with the geographical distance between them. In the fields of regional economics, economic geography, geography of innovation, and knowledge transfer, the GM was used extensively in studies on co-inventors (Maggioni et al, 2007; Ponds et al, 2007), co-authorship and citations (Peri, 2005; Fischer et al, 2006), R&D collaborations (Scherngell & Barber, 2009), and inventor mobility (Miguelez & Moreno, 2013). In the majority of the studies that use GM, the unit of analysis is a spatial one (cities, regions or countries), while in few of them the organizational or individual levels are employed (Breschi & Lissoni, 2009).

The GM can be extended to study panel data, so that it can introduce the time aspect into relational structures. It can also include other factors that affect network structures. In the same time, there are some serious problems in the specification of the OLS of the GM. The OLS does not control for dependencies in the network data, nor can model them, leading to biased estimations. From the estimation of gravity equation two main biases arise: the omitted variables bias and the clustering of error components. Several extensions and modifications of the GM appeared to deal with the dependency issue; however they result into very complex and computationally intensive methods.

The Exponential Random Graph Models (ERGM) are well established in many fields, and among them sociology and political science. However, they are not so frequently used into the analysis of knowledge networks, with only a small number of studies using them (Broekel & Hartog, 2013a; 2013b). ERGMs are stochastic models that define the creation of ties as continuous process through time. The empirically observed network is only one instance of multiple (large number) possible alternative networks, with similar characteristics, and is the result of a stochastic procedure. The difficulty with stochastic models for social networks is that they have to represent dependence and they cannot build independency assumptions. Other restrictions are that they are used for digraphs (binary data), they control for actor differences and reciprocity, which may not always be sufficient, and that their estimation is time consuming due to goodness-of-fit tests they perform. Although ERGM require some experience in model specification and estimation, their advantage is that they represent details of the network structure. Recently several extensions of the ERGM have appeared (Hanneke & Xing, 2007; Cranmer & Desmarais, 2011; Krivitsky & Handcock, 2014) that allow the use of longitudinal network data for estimations with discrete-time network evolution.

The Stochastic Actor-Oriented Models (SAOM) has started recently to emerge in the fields of regional economics and economic geography. Given its actor-oriented nature, this method is particularly suitable for modeling the evolution of knowledge networks. It is implemented both in global knowledge networks of R&D collaborations, co-invention, and advices (Balland, 2012; Balland et al, 2013; Ter Wal, 2013) and in knowledge networks within regions or clusters (Giuliani, 2013; Broekel et al, 2014). The SAOMs are statistical models that were developed specifically for the analysis of network dynamics, while the most known one was introduced by Snijders (2001). The dependent variable in an SAOM is the structure occurring from relationships between a set of actors, for example how the relationships between actors are organized. More precisely, SAOMs simulate network evolution between actors and calculates the parameters of the underlying mechanisms of network dynamics with the combination of discrete choice models.

SAOMs are based on the idea that actors can change their relationships (ties) with other actors at stochastically determined moments (Snijeders et al, 2010). For its estimation, the SAOM is based on certain underlying assumptions that are related to the modeling of the evolution of network structures as a time-continuous Markov chain, resulting by probability choices of actors. A Markov chain is a dynamic process where the network of a second time (t+1) is generated in a stochastic way from its structure in a previous time (t). The implication of this assumption is that the probabilities of change depend exclusively on the current state of the network and not on the past ones. As the memory of the past states is important, it is crucial to include exogenously the appropriate variables that can capture relevant information (Steglich et al, 2010). A second assumption is that the time between observations is continuous, which implies that the change observed is the result of an unobserved number of micro-steps. So, at every micro-step, actors can change only one tie at a time, and additionally a group of actors cannot start relationships at the same time (t). The third and most important assumption is that the dynamics of the network are based on the choices of the actors depending on their constraints and preferences. This makes the analysis of economic networks more realistic, but for knowledge networks, the access of actors to knowledge has to be modeled as well. So, what is modeled in reality is the decision of an actor to create a tie. In the case of directed networks though, it means that the actors in the end of the tie are not able to decide. This implies that this last assumption is not plausible, when actors are not able to make their strategic decisions.

The last empirical strategy presented in this chapter is the Multiple Regression Quadratic Assignment Procedure (MRQAP). This method is extensively analyzed as it will be used for the analysis of the data of the present research. In the fields of economic geography and knowledge networks, the dependent variable under analysis is the intensity of knowledge exchange ties between units, either these are individuals, organizations, or spatial units, like cities or regions. MRQAP is a purely statistical approach for structural dependencies among network (relational) data. The MRQAP can deal with both continuous (OLS) and binary (logit) dependent variables and takes into account their inherent interdependencies when calculating their statistical relevance.

A small number of studies apply MRQAP to inter-organizational and knowledge networks, as it only recently it appeared as a method for analyzing in the literature of regional economics, economic geography, and knowledge transfer. One of the first studies on the field is the one of Bell (2005), who used a bivariate quadratic assignment correlation to obtain statistical conclusions for the correlations between friendship, information, and advice relationships among CEOs. Another widely known study that used MRQAP is that of Cantner and Graf (2006), who studied the intensity of networks of inventors by co-patenting data. Then, Maggioni and Uberti (2007) studied the relationship between regional flows of EU funded R&D collaborations, internet hyperlinks, co-patenting, and the flow of Erasmus exchange students. One of the most recent studies is the one of Broekel and Boschma (2012), who explores the relevance of several kinds of proximity (cognitive, social, institutional, and geographical) on a knowledge network of the aerospace industry of Netherlands.

Historically, the quadratic assignment procedure was introduced by Mantel in 1967 for identifying non-random time and space clustering of disease (Mantel, 1967). The basic concern of Mantel was the simultaneous clustering of the disease in space and in time. Although there were several statistical tools that were handling spatial or temporal clustering, there was still the challenge of two-dimensional occurrence of clustering. Thus, Mantel proposed the estimation of the uncorrected correlation coefficient in these two dimensions. Still remaining was the problem of the high autocorrelation, so Mantel constructed a repeated dataset of permuted rows and columns of the two matrices that correspond to the null hypothesis of no correlation. Although the Mantel's test was developed in the beginning for the identification of disease clusters, the procedure could easily be applied to different contexts (Mantel, 1967). The notion and term of "quadratic assignment procedure" was introduced by Hubert and Schultz (1976) to describe the Mantel's test. From this point the statistics of QAP were developed and enhanced in a number of ways, with most important approach the one of Krackhardt (1987; 1988), which extended QAP methodology to test the relationships between multiple relational matrices in a regression (MRQAP). Since then, the MRQAP was under multiple refinements, among which the most important is the one of Dekker et al (2007) that deals with multicollinearity and autocorrelation issues.

In practice, the QAP regression is the combination of Mantel test and the OLS or Logit model, with the dependent variable to be a matrix of relations between actors. The statistical context applied depends of the nature of the network data. For a valued network, the OLS is appropriate, while a Logit model is suiting to binary network data. The independent variables are again matrices whose influence has to be tested on the dependent one. The problem of the network data is that the estimations are suffering from structural autocorrelation, which makes the standard statistical tools biased and invalid. Therefore, Krackhardt (1987; 1988) proposed to make no assumptions for dependency, and to compare the statistics of the actual regression with the distribution of such statistics occurring from a large number of simultaneous row/columns permutations of the variables. So, QAP is a permutation (randomization) based semi-parametric test of dependencies between two matrices (variables) of the same dimensions. Thus, the estimation of the p-value is done according to the frequency that the statistic values in the reference distribution are equal or larger than those of the empirically observed regression (Dekker et al, 2007). 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.

The most used approach of applying the QAP for inference on multiple regression coefficients (MRQAP) is the double-semi-partialing approach of Dekker et al (2007). The difference with the original MRQAP is that the effects of other explanatory variables are partialed out from the effect of a main explanatory variable. As Broekel et al (2014) (p. 432) are explaining "the resulting residuals are subsequently QAP-permutated and included in a regression of the dependent variable on all explanatory variables but the focal one giving the reference values for the test statistic" The approach of Dekker et al (2007) can be applied in both OLS and Logit regression analysis, and the interpretation of the coefficients depends on the type of regression used.

After having presented the four main statistical methods for analyzing network data, it is important to understand the criteria according to which the one or the other method is more suitable. There are several issues that can be considered as criteria for choosing the statistical method suitable for analyzing network data: the type of the relational data, their size, and the dynamics of the network, the independent variables of interest, and the practical considerations.

- The first criterion has to do with the difference between purely relational and network data. For the first kind the assumption for independency holds, so there is no need to take into account the network interdependencies, and the GM is more suitable. However, this assumption is not valid for knowledge transfer within inter-regional networks formed by social processes.
- Considering the type of network to be analyzed, there are two concerns: the type of research unit and the mode of the network. There are two groups of networks according to the type of research unit: those constructed from links between actors (individual or organizations), and those constructed from links between geographical units (regions or countries). SAOMs are developed especially for the first type, while GMs are preferred for the second. ERGM are somewhere in between, while MRQAP is a statistical procedure measuring relations between the units that can be any of the two types. Also, a network can be one-mode or two-mode (bipartite) in nature. The observation of direct interactions between actors results to the construction of one-mode networks, while in practice two-mode networks are more

common. In the latter no direct interactions are observed, but the actors are participating in common events. GM and MRQAP handle one-mode networks, while ERGM and SAOM can handle directly two-mode networks.

- A practical issue is the size of the networks of interest. GMs can analyze large networks, while the rest are computationally intensive, so for limited number of nodes, depending the software and hardware used.
- In the representation of dynamic networks, SAOMs have an advantage for analyzing network dynamics as they were created for this purpose. However, GM and ERGM developed extensions for using longitudinal data. Finally, MRQAP can study the effect of a temporal event on the evolution of the network by dividing it in two or more time periods.
- For analyzing the geography of knowledge networks, all the four models can be used. However, the models differ in their ability to consider factors at the node and structural level. Node-level actors can directly be included in the GM, ERGM and SAOM frameworks, while ERGM and SAOM are able to incorporate simultaneously node, dyad, and structural level factors (triadic closure). From this point of view, the MRQAP appears to be the most restricted model, as it only allows the consideration of dyad level variables (relationships between actors). However, this shortcoming of MRQAP can be overcome, by translating the node and structural level factors to the dyad level.
- Finally, although ERGM and SAOM have higher applicability and power (followed by GM), they also have higher complexity. From this aspect MRQAP has the advantage as it is simple and accessible (Dekker et al, 2007). Also, despite the fact that ERGM and SAOM are advanced in many ways, they remain limited in simple issues. Another advantage of GM and MRQAP is their wide range of goodness-of-fit statistics.

Taking into consideration these six criteria, the present research has employed MRQAP for analyzing the network data on ICT collaborative projects for the region of Trentino. The practical issues and the simplicity of the model played an important role to the selection of the method; however the main reasons concern the dyadic structure of the data, and the nature of the research questions posed. The networks under research in this study are one-mode networks measuring relationships between actors that collaborated in ICT projects and are located in Trentino. The analysis will control three different types of relationships (collaboration, coordination, and funding) which imply knowledge transfer, while the attributes of nodes and structure were translated to the dyadic level (cases that the actors have the same characteristic). Also the questions that derived from the gaps of the literature have to do with the strength of the ties and the effect of temporal events in it, so the MRQAP is considered more suitable for analyzing amounts of flows and interactions between actors.

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CHAPTER 5

EMERGING ICT REGIONAL INNOVATION SYSTEMS AND KNOWLEDGE FLOWS: A CONCEPTUAL FRAMEWORK

In the last three decades the academic focus turned to the regional aspect of innovation systems. The argument on this topic triggered the interest of policy makers at national and regional levels, in order to determine the mechanisms under which the process of innovation creation takes place. Despite the different spectra under which systems and regional systems of innovation are analyzed, and the discussion raised on this subject, all the researchers, policy makers, and regional, national, and supra-national institutions agree on one thing: knowledge networks are indispensable part for the analysis of agglomeration economies (Edquist, 1997; Autio, 1998; Cooke, 2002; Doloreux & Parto, 2005; Stuck et al, 2015).

Several academics attempt to describe the RIS by placing it into a conceptual framework, and drawing the creation and transfer of knowledge inside it (Cooke, 2002; Autio, 1998; Stuck et al, 2015). As discussed in Chapter 2, the focus of these frameworks concentrates either on the groups of actors interacting for knowledge generation and diffusion (Fischer, 2001) or on the geographical distance of these actors (Bathelt et al, 2004). However, the existing frameworks treat the knowledge network as an one-dimensional element of the RIS, disregarding its complex and multidimensional nature.

The present research aims to study in depth the knowledge network of an emerging RIS, taking into account and disentangling its different dimensions and levels of analysis. This chapter provides a conceptual framework of analysis of the multiple dimensions that the knowledge network of an RIS owns. In section 5.1, I propose a schematic representation of the knowledge network along three axes: vertical, horizontal, and time axes. In the next section (section 5.2), there is the representation of the ICT knowledge network of Trentino, allocating the data to the previously analyzed conceptual framework. The detailed analysis of the Trentino ICT knowledge network follows (section 5.3). This analysis aims to identify the structure and the key actors of the regional knowledge network, as well as to test how a possible failure of one or more key actors would affect the knowledge network. Finally (section 5.4) conclusions and policy implications are presented.

5.1 The Conceptual Framework

Based on the literature on RIS (Cooke 2001; Fischer, 2001) and knowledge spillovers (Breschi & Lissoni, 2001; Bathelt et al, 2004; Gachino, 2010), I would like first of all to allocate the present research in a conceptual framework. The literature has produced until now several conceptual frameworks in order to describe knowledge networks, so as the spillovers and flows produced inside, from within and towards the RIS (Cooke, 2001; Fischer, 2001, Bathelt et al, 2004). The boundaries and institutional framework of RIS were set two decades ago by classifying the RIS according to their characteristic and potential (Cooke et al, 1997; Cooke, 2001). A generalized framework was introduced by Fischer (2001), dealing with the localized input-output relations, the knowledge spillovers, and the interdependencies between the actors of the RIS knowledge network. This framework presents the major building blocks of the knowledge network of an RIS (Figure 3, Chapter 2), however it cannot help with the micro analysis of the knowledge relations developed inside the network. More focused on knowledge transfer issues is the framework provided by Bathelt et al (2004). Although, the authors talk about clusters, they introduce the notion of knowledge transfer and the differentiation between local and extra-local relationships (Figure 4, Chapter 2). Still, they focus on the geographical proximity of the actors and the framework cannot describe the multiple kinds of relationships in different levels of analysis.

Thus, a multidimensional framework is needed in order to depict the dynamics developed inside the knowledge network and the spillovers that possibly these dynamics produce. The knowledge transfer within the RIS is represented as relationships between actors, like a network of sub-networks and communities. By the point of view of a network, every actor is represented by a node with its attributes and every relationship by a tie. To represent the dynamics of the network and the multiple levels, I introduced three axes of analysis of the RIS knowledge network: the vertical, the horizontal, and the time axes.

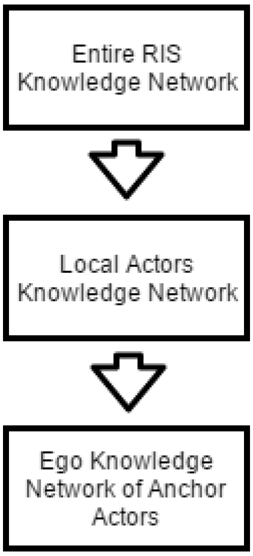

Figure 10: Vertical Axis of Analysis. Getting deeper into the different levels of analysis of the knowledge network of an RIS

The vertical dimension of the analysis (Figure 10) gets deeper into the knowledge network geography, analyzing it at multiple levels. In the present framework three different levels of analysis are introduced. They describe the knowledge network, from the entire universe of actors until the ego-network of one influential actor. The first level is the complete knowledge network, including all the actors that participate in the knowledge transfer process and all the types of relationships that can indicate knowledge transfer. When the knowledge network of an RIS is studied, the sampling of actors is not a good practice, as important information can be omitted (Cantner & Graf, 2006). Therefore, the complete population of actors taking part in the knowledge network of the RIS has to be included in the analysis. The second level of analysis is the knowledge network of the local actors. This level includes only the actors based inside the geographical borders of the RIS and are connected with the complete set of relationships that indicate knowledge transfer. This level represents in knowledge transfer terms the local buzz (Bathelt et al, 2004). The third level is the actor level. It is depicted as the ego-network of every actor, including all the kinds of relationships that can indicate knowledge transfer from and towards the actor. However, there are actors more influential than other actors and their existence and activity in the knowledge network can affect several other actors, or even the whole knowledge network. These actors in the literature are known as anchor actors or anchor tenants (Niosi & Zhegu, 2010; Robinson et al, 2007; Agrawal & Cockburn, 2003).

The analysis of the RIS knowledge network in different vertical levels is important, as every level conveys very different information and policy implications. The study on the entire network tells how successful are the local organizations in creating connections with actors outside their area and, therefore, in being potentially able to import knowledge and innovation from distant markets and systems. The analysis of the local actors' knowledge network is important because it allows assessing the diffusion within the region, of collaborative projects and the propensity of local actors to collaborate among them. Finally, the ego knowledge network allows studying the role of some major, pivotal actors on the whole network.

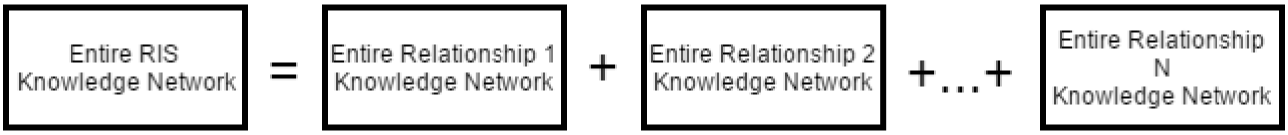

Figure 11: Horizontal axis. The knowledge network as sum of relationships

The horizontal dimension of the analysis (Figure 11) consists of a finite number of relationship types indicating knowledge transfer. The number of all the relationships of all the types formed inside the RIS being summed up are equal to the number of ties of the entire knowledge network (Figure 11). Every kind of relationship represents different aspect of knowledge transfer. There are two categories of interactions between actors: the formal and informal. The formal interactions are documented and recorded. Examples of formal relationships are the co-authorship, co-patenting, common participation in projects, joint ventures etc. (Inkpen & Tsang, 2005). On the other hand, the informal interactions are spontaneous and often not recorded. Examples of the second category can be the friendship, mentoring, advice seeking etc. (Inkpen & Tsang, 2005). However, not all relationships that indicate knowledge transfer can be traced easily. In opposition to the actors, in terms of network the relationships can be sampled depending to the subject and the aim of the research, without losing important information of the network activity (Cantner & Graf, 2006). The classification of the relationships inside the knowledge network is important because each typology of interaction conveys different policy implications. The two dimensions (vertical and horizontal) of the analysis are presented to the Figure 12 below consist a two dimensional conceptual framework of the knowledge network inside the RIS.

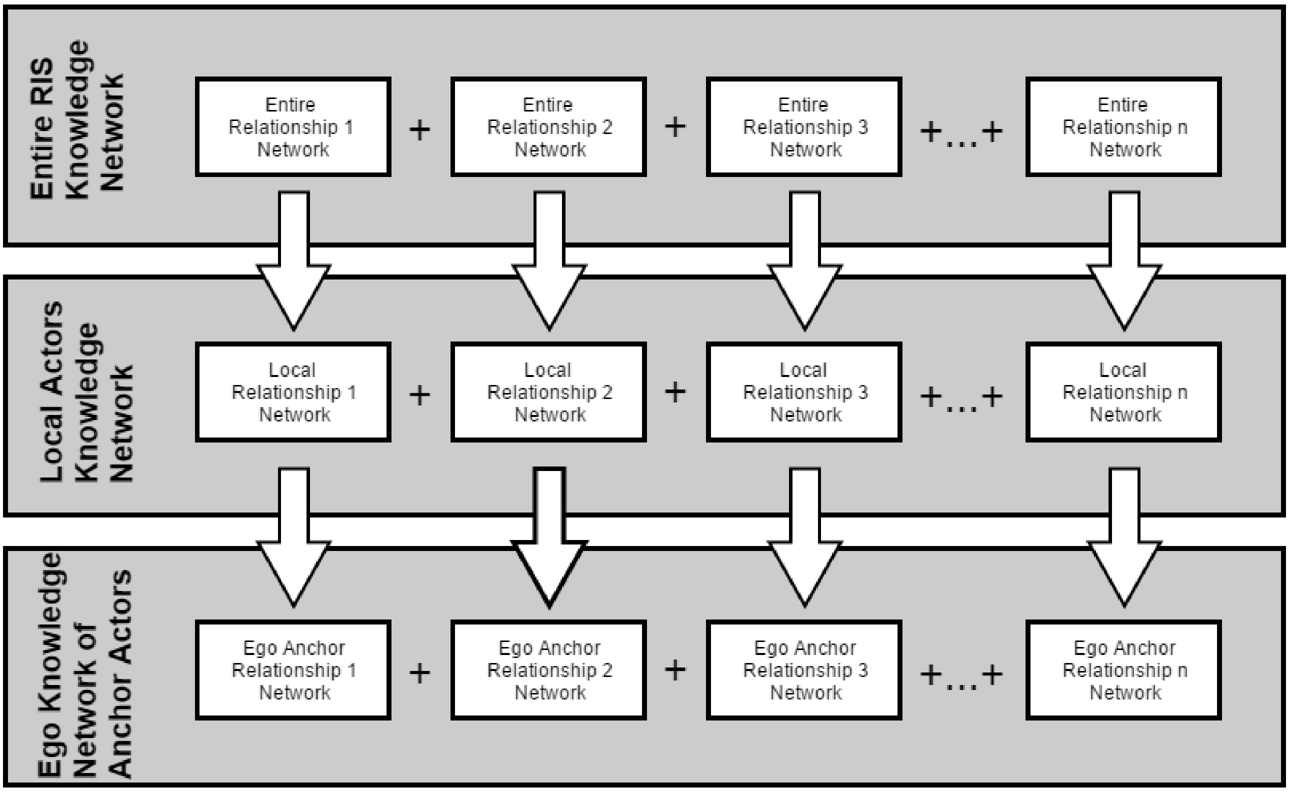

Figure 12: Two dimensional conceptual framework of knowledge transfer inside the RIS

In Figure 12 the grey rectangles represent the vertical axis of in depth analysis of the RIS, while the white rectangles represent the sum of relationships of the horizontal axis that constitute every level of analysis. The three levels presented in the vertical axis can be used to analyze each one of the relationships that indicate knowledge transfer between actors.

Figure 13: Time axis. The evolution of knowledge network of an RIS

The framework described in Figure 12 is static, i.e. it represents the knowledge network at a certain points in time. One of the aims of this work, however, is to depict the temporal dynamics in the evolution of RIS. Thus, a third dimension, the temporal one, is introduced (Figure 13). Until now the literature gives static images of the knowledge network (Gluckler, 2007; Ter Wal & Boschma, 2009), while really few scholars studied the dynamics of the network in time (Cantner & Graf, 2006; Broekel & Boschma, 2012; ter Wal, 2013). The idea of the static image of a knowledge network used in the literature until now produces a "snapshot" of the network in a fixed moment in time. In order to introduce the time axis, the reader has to imagine the RIS evolution as "video" with the static images of the network in discrete moments in time as "time frames". So, for every time (t) there is an equivalent image either of the entire knowledge network or of each one of its sub-networks described in Figure 12. Given the cumulative nature of knowledge (Breschi & Malerba, 1997; Fischer, 2001; Morgan, 2004; Antonelli, 2007), another approach to the temporal dimension is the perception of time as continuous "interrupted" by independent or guided events. Thus, the effect of these events to the knowledge network can be explained by the image of network after the event. A further analysis of this approach with empirical data is presented in Chapter 6 of this thesis.

5.2 Data and Methods

In order to represent the knowledge network of Trentino, the data on ICT collaborative projects described in Chapter 4 were used. Compared with the conceptual framework discussed in the previous section (5.1), the ICT knowledge network is a subset of the whole RIS knowledge network. Innovation in Trentino occurs obviously in a number of other sectors (wine, tourism etc.). In the present work the analysis is focused on the ICT sector for the reasons discussed in Chapter 3. I was able to trace all the ICT collaborative projects of which at least one participant is located inside the region of Trentino. Every project has the form described in Chapter 4 (Table 2), so the participants/actors can be depicted as nodes and the relationships between them constitute the entire knowledge network of Trentino ICT innovation system. The underlying structure in projects permits the mapping of the RIS as network of sub-networks and communities. SNA was used to map, describe, and analyze the Trentino ICT innovation system, according to the conceptual framework explained in the previous section. In this way the reader can form an idea of the complex interactions taking place inside the RIS, forming the relationships between the actors and constituting the knowledge network in multiple levels.

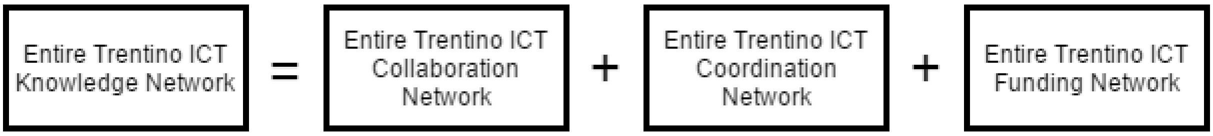

Figure 14: Horizontal axis. Trentino ICT knowledge network as a sum of relationships

The first dimension analyzed is the horizontal one (Figure 14). The set of relationships examined are all official relationships deriving from the organization of the data into projects, indicating knowledge transfer between actors and foster innovation. The types of relationships (Figure 11) that constitute the ICT knowledge network of Trentino are three: the collaboration, the coordination, and the funding. Respectively, these three official relationships form "slices" of the original knowledge network, or in other words, they form sub-networks (Figures 15a, 15b, and 15c, the figures in one-page format can be found in the Appendix) of knowledge transfer, and their construction is based on three assumptions.

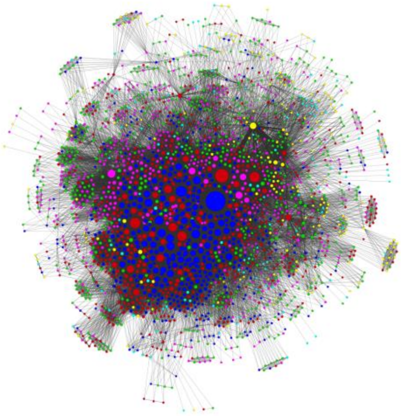

Figure 15a: Entire Trentino ICT Collaboration network

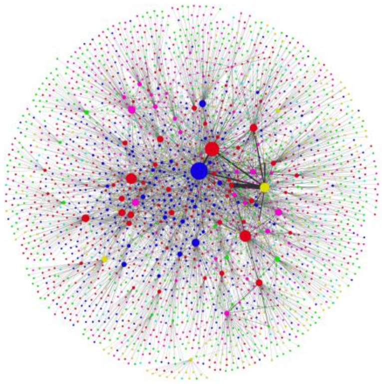

Figure 15b: Entire Trentino ICT Coordination network

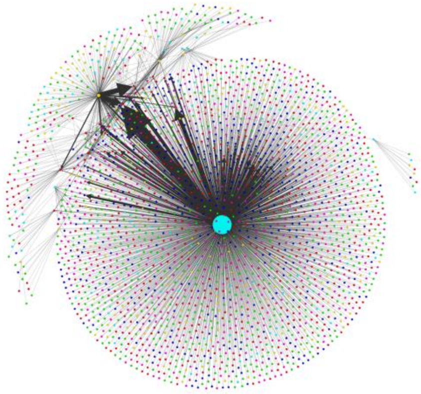

Figure 15c: Entire Trentino ICT Funding network

The *collaboration relationship* derives from the interaction through the partnership in the same research project. All the actors participating in a project are interacting with each other. The first assumption is that in the collaboration network the knowledge flows freely among the actors of every project, so all actors in a project receive the same amount of knowledge and absorb knowledge from every other actor in the same project (Inkpen & Tsang, 2005; Oshri et al, 2008; Wenger, 1998). The knowledge is considered reciprocal and cumulative, which means that it does not disappear after the end of the collaboration but it is accumulated to the organizational memory of the participants (Antonelli, 2003; 2007; Fischer, 2001; Breschi & Malerba, 1997; Morgan, 2004) (Figure 15a).

The *coordination relationship* is built by appointing one of the actors of the project as coordinator, and the interactions that this coordinating actor has with the rest of the participants. The assumption made is that in the coordination network, the existing and produced knowledge in every project is distributed to the rest of the participants by the coordinator of the project (Muller & Zenker, 2001; Huggins et al, 2008; Phelps et al, 2012; Fritsch & Kauffeld-Monz, 2010; Cerulli et al, 2016). So, the knowledge circulating is managed and gathered by the coordinating actor. Again in this case, the knowledge is considered reciprocal and cumulative (Figure 15b).

The third relationship, the *funding*, derives from the identification of a funding entity in the project, and can give valuable information about the source of money and its destination(s)

(Agrawal, 2001; Agrawal & Henderson, 2002; Landry et al, 2007). The last assumption is that in the funding network, when an actor funds a project acts like an available pool of knowledge and asks for knowledge in return for its funding from the participants of the project. In this case, the knowledge is considered cumulative, however inflows and outflows can be distinguished (Figure 15c).

Figure16: Vertical Axis. Trentino ICT knowledge network in three levels

In terms of vertical dimension, three levels of the Trentino ICT innovation system are analyzed (Figure 16): the *entire* Trentino ICT knowledge network, the *local* Trentino ICT actor knowledge network, and the *ego* knowledge network of the anchor ICT actors in Trentino RIS.

The first level (the entire network) represents the entire ICT knowledge network of Trentino, using data on ICT collaborative projects of which at least one participant is located in Trentino. This level includes all the actors, using both the partitions described in Chapter 4; the one of location and the kind of organization which the actors belong to. The first partition differentiates the actors by their location (local, national, and international) as this was described in Chapter 4, and the second partition divides the actors according to their organizational form (universities, research centers, large firms, SMEs, public agencies, and other kinds), also in the way described in Chapter 4. The total number of actors in the entire Trentino knowledge network is 2,394.

The second level of analysis is the local ICT knowledge network (Figure 16). In this level, the local actors of Trentino ICT innovation system are isolated, keeping the partition of the organizational kind. So, it is possible to have an image of the so-called "local buzz" (Bathelt et al, 2004) inside Trentino and how the knowledge between the local actors is transferred. The number of all local actors participating in knowledge generation and transfer on ICT in this RIS is 157.

The third and deeper level of analysis is the ego-network of the key anchor actors of Trentino ICT innovation system (Figure 16). In this level, the ego-network of the key influential actors of the RIS is isolated. From the descriptive analysis, an influential core appears in the center of the RIS. The three anchor actors constituting this core are the local university, the biggest research center of the region and the local government itself. One by one, the ego-network of these actors were isolated, and then subtracted from the network, in order to understand the influence they have in the knowledge network of the region.

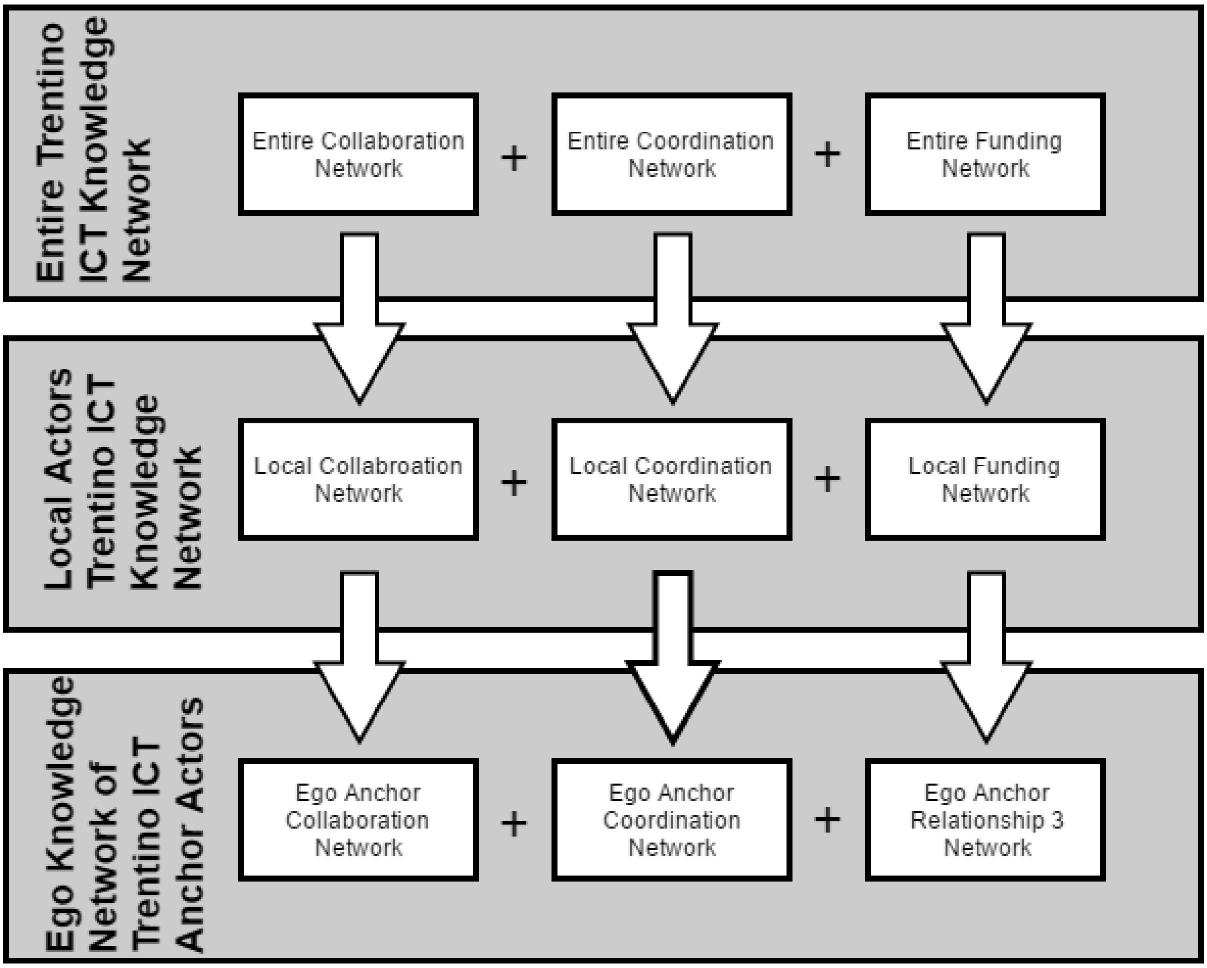

Figure17: Trentino ICT data allocated to the two axes conceptual framework for the knowledge network of the RIS

Allocating the dataset to the two axes framework described above, I was able to analyze the Trentino ICT innovation system and the different relationships formed among the actors in multiple levels (Figure 17). For every level of analysis, the networks representing every relationship were formed, and for every relationship (collaboration, coordination, and funding) the actors were analyzed in three levels (entire, local, and anchor actor levels). In this way, nine networks were formed, each of them describing a different aspect of the RIS in terms of level of analysis and the describing relationship. This procedure gives a global idea of the role of actors, their attributes, and the relationships formed between them, in the innovation process.

5.3 Definition of the Measurements

In social networks the standard univariate statistical measures, like average or variance, allow the analysis of every actor separately considering the way that it is connected to other actors with ties. However, these measurements do not permit the analysis of the network as a whole (Hanneman & Riddle, 2005; Wasserman & Faust, 1994). Thus for proceeding to the analysis and comparison of the different networks of relationships and levels of the knowledge ICT network in Trentino, a set of different measurements were extracted with the help of the SNA software of Gephi (Bastian et al, 2009) and UCInet (Borgatti et al, 2002). These measurements are the average degree, the average weighted degree, the network diameter, the graph density, the network centralization, the average clustering coefficient, and the average shortest path length. In order to identify, also, the key and leading actors inside the knowledge network, and to measure their relational value considering their position, another set of measurements was extracted for every actor. These measurements are the degree, betweenness, closeness, and eigenvector centralities.

The average degree is the average number of links per node, while average weighted degree is the average sum of weights of the edges of the nodes. In case of not merging the existing multiple edges from one node to another into one weighted edge, then these two measurements are equal. So, the weight of the edge is equal with the times that two specific actors have cooperated with each other.

The diameter of the network is the maximum distance between any pair of nodes in the graph. So, it describes the maximum potential number of intermediate nodes from every actor to any other actor in the network.

The density of a network is defined as the total number of the existing ties divided by the total number of all possible ties in the network, $D = \frac{2E}{N(N-1)}$ (where E is the number of existing ties and N is the number of nodes).

The degree centrality (C_D) of an actor (explained more explicitly below) is the number of the ties that this actor has with other actors, while the network centralization measures how central is the most central node considering the centrality of the rest of the nodes, $C_D(G) = \frac{\sum_{i=1}^{g}[C_D(N') - C_D(i)]}{[(N-1)(N-2)]}$, (where G is the network, N' is the node with the highest degree centrality in the network and N is the number of nodes) (Freeman, 1978).

The last structural measures calculated are the network clustering coefficient and the average shortest path length. The clustering coefficient of a node measures how much the neighbors of the node tend to become a clique (a closed network with ties from all the nodes to all the neighboring nodes), $C = \frac{number\ of\ closed\ triplets}{number\ of\ connected\ triplets\ of\ nodes}$ (where a connected triplet is a connected sub graph of three nodes and two ties), while the average network clustering coefficient is the average of the clustering coefficient of all the nodes of the network, $\bar{C} = \frac{1}{N}\sum_{i=1}^{N} C_i$ (where N is the number of nodes) and calculates the degree in which the nodes in a network tend to cluster together (Watts & Strogatz, 1998). The average shortest path length is the average number of steps along the shortest paths of all possible combinations of nodes of the graph.

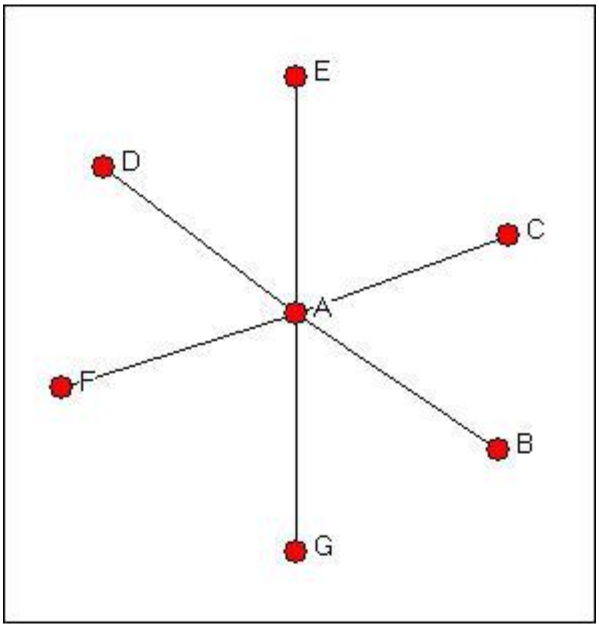

Figure 18: The star network topology (Picture taken from Hanneman & Riddle, 2005)

The above measurements can describe the topology of the network in the meso and macro level. Three kinds of topologies are observed in the ICT knowledge network of Trentino. Starting from the simplest one, the funding network of Trentino ICT innovation system tends to star topology (Figure 18). This is extensively supported from the data analyzed in a later section. In its simplest form, a star network consists of one central node (which can be called hub) and all the rest of the nodes connected to this central node with a point-to- point connection (Freeman, 1978). It is characterized by high degree of network centralization. So, all the nodes of the network in order to communicate have to use this node as intermediate. The advantage of this topology is that if the interaction with one of the nodes stops, this doesn't affect significantly the flow of knowledge/funds inside the network. However, if a failure in the central node happens, then, all the nodes of the network become isolated.

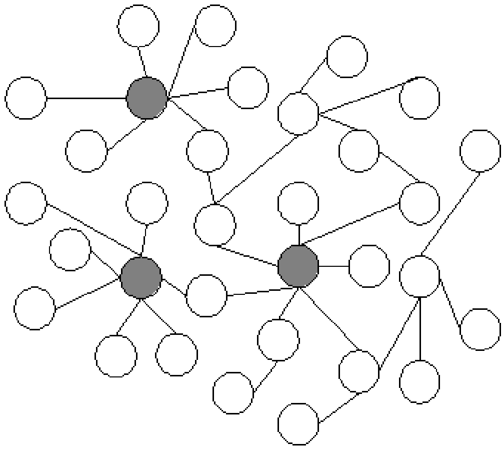

Figure 19: Scale-free network topology.

The second form of network organization is the scale-free one (Figure 19) that characterizes the coordination network of Trentino ICT innovation system (also supported from the data in the analysis section of this chapter). According to Barabasi and Albert (1999) a scale-free network is a random network whose degree distribution follows the power-law asymptotically. The most notable characteristic of a scale-free network is the existence of few nodes that have degree considerably greater than the average. These nodes are called hubs and they perform a specific role in the network. In the coordination network they perform the role of the coordinator of projects, distributing and absorbing the knowledge produced by the rest of the participants. The hubs are simultaneously the strength and the weakness of the network. They are the strength because if a mistake or a malfunction occurs in one of the low degree nodes, the rest of the network is slightly affected. However, they are a weakness as if one of the hubs stops performing, then a big part of the network remains disconnected or a big number of nodes become isolated (Cohen et al, 2000). Another important characteristic of this kind of networks is that as the degree of the nodes increases, their clustering coefficient decreases. This implies that the low degree nodes belong to densely connected sub-networks that are connected to each other through hubs.

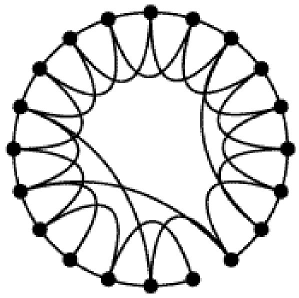

Figure 20: Small world network topology (Picture taken from Watts & Strogatz, 1998)

The last form of network organization is the small-world topology (Figure 20) and it characterizes the collaboration network of Trentino ICT innovation system. Again the measurements in the analysis section below support this argument. A small-world network is a type of network in which the majority of actors are not collaborating with one another, but the collaborators of any given actor are likely to collaborate with each other, and most actors can be reached by a small number of steps (Watts & Strogatz, 1998). Small world networks tend to contain cliques, or near cliques, meaning sub-networks and tightly knit communities which have connections between almost any two nodes within them (Watts & Strogatz, 1998). This results to the high clustering coefficient of the network. This structure also confirms the presence of high degree nodes in the network which serve as mediators in the short path length of other nodes in the network. According to Watts and Strogatz (1998), knowledge diffuses faster to small-world networks structure, as every actor in the network can be reached within a small number of steps. In order to distinguish the small-world topology in a network, it is possible to compare the network under study with a random graph with the same number of nodes. In the two graphs the average shortest path length is similar, while the average clustering coefficient of the small-world network is significantly higher than the average clustering coefficient of the random one.

Considering the micro level of the knowledge network of the Trentino ICT innovation system, a set of measurements for every node of the network was calculated, as mentioned above. These measurements help to identify the key actors inside the RIS and their value considering their relational position in the network. These measurements are the different kinds of centrality for every node. The first measure extracted is the degree centrality (C_D). Degree centrality is the conceptually simplest measure of centrality, since it is defined as the number of edges incident upon a node, or in other words, the number of ties that a node has (Freeman, 1977). In directed networks (networks with inflows and outflows) the degree centrality is distinguished in in-degree and out-degree centralities. The in-degree centrality is the number of ties directed to a node, while the out-degree centrality is the number of ties that a node directs to other nodes. Degree centrality is a measure of popularity in the social networks, signifying the number of actors that an actor can influence directly.

Closeness centrality is defined by Freeman (1978) as the sum of the length of the shortest paths between a node and all the other nodes in the network. So, the more central an actor is the most close it is to all other actors. The used version of closeness centrality is its normalized form, that is: $C_C = \frac{N}{\sum_y d(y,x)}$, where d(x, y) is the distance (in steps) between the nodes x and y, and N is the number of nodes in the network. This measure cannot be applied to networks with disconnected components as the distance between them is infinite (Wasserman & Faust, 1994; Opsahl et al, 2010). However, in the entire RIS of Trentino there are neither disconnected components nor isolate actors.

Betweenness centrality is an indicator of node centrality that is equal to the number of shortest paths from all the nodes to all the others that pass from a specific node (Freeman, 1977). The betweenness centrality of a node is given by the formula: $C_B = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$, where σ_{st} is the total number of shortest paths from node s to node t, and $\sigma_{st}(v)$ is the number of those paths that pass from node v. In social networks, and especially in knowledge networks a node with a high betweenness centrality has a large influence on the transfer of knowledge in the network. Also, the high betweenness centrality is closely associated with high connectivity in a network. Thus, nodes with high betweenness centrality can result in the isolation of a part of the network.

Finally, the eigenvector centrality constitutes a measure of the influence of a node in the network (Newman, 2008). It is an extension of the degree centrality, however it measures the importance of the nodes connected to the node under investigation. It assigns relative scores to all the nodes in a network based on the assumption that connections to high-scoring nodes contribute more to the node under study than connections to low-scoring nodes. The mathematical formula of eigenvector centrality is: $C_E = \frac{1}{\lambda} \sum_{t \in M(v)} x_t = \frac{1}{\lambda} \sum_{t \in G} a_{v,t} x_t$, where G is the network under study, $a_{v,t}$ is the adjacency matrix that equals to 1 if v is connected to t, otherwise equals to 0, M(v) is the set of neighbors of the node v, x_t is the centrality of the node t, and λ is a constant. In social and knowledge networks, the eigenvector centrality contributes in specifying the contribution of each node to the network, as not all connections are the same.

5.4 Results of Analysis

In order to understand and analyze the structure of ICT innovation system of Trentino according to the conceptual network presented above, a set of comparisons are deployed.

First of all, I compare the networks produced in horizontal axis for every level of analysis (Tables 3, 4, 5, 6, 7) and visualize them (Figures 15 (a, b, c), 21 (a, b, c), 22 (a, b, c), 23 (a, b, c), 24 (a, b, c)), the figures can be found in full page format in the Appendix). The analysis of the networks is done in terms of overall network measurements and key actors identification according to the centrality measures (Tables a1-a4, b1-b4, c1-c5, Appendix). As a last step, I identify the anchor actors in Trentino ICT innovation system and compare the network resilience in case of their presence or absence.

Table 3: Overall knowledge network measurements of Trentino ICT Collaboration, Coordination and Funding Networks

	Entire Collaboration Network	Entire Coordination Network	Entire Funding Network
Nodes	2394	2394	2394
Edges	46148	4090	2717
Average Degree	38.553	3.417	1.135
Average Weighted 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)

Table 3 presents the overall network measurements for the three different networks deriving from the relationships described in the horizontal dimension of the conceptual network (i.e. collaboration, coordination, and funding) presented above and for the first level of the vertical dimension of analysis (i.e. the entire network, Figure 17). None of the networks demonstrates isolate nodes, as all nodes are connected in one giant component. Comparing the average degree (AD) across networks, the average degree of the Entire *Collaboration* Network, it is significantly higher than the one of the Entire *Coordination* Network and Entire *Funding* Network. This is due to the underlying structure of the collaboration networks in projects. The AD in comparison with the average weighted degree (AWD) in the Entire *Collaboration* Network is about 13 percent smaller, pointing out the amount of average repeated collaborations. The same holds with the comparison of the AD and AWD of the Entire *Coordination* Network, where the amount of the average repeated coordinating relationships is 11 percent lower. The same indicator is considerably higher for the Entire *Funding* Network, implying the repeated funding between funding entities and funded actors.

The network diameter of the Entire *Collaboration* Network is considerably smaller than the other two networks, as a consequence to its topology of small world, allowing the fast access to most peripheral nodes of the network. All three networks appear to be rather sparse. The Entire *Coordination* Network appears to be less centralized than the other two networks. This implies the existence of few high degree nodes inside the network (hub) connected with a high number of low-degree nodes, reflecting the accumulation and management of knowledge by certain actors of the knowledge network. On the contrary, the Entire *Funding* Network is highly centralized. This measure implies the existence of a main big funding entity, funding the majority of actors; on the other hand, the fact that the network centralization is not exactly equal to one, is explained by the existence of smaller funding entities in the knowledge network of the RIS. The Entire *Collaboration* Network presents high average clustering coefficient compared to the other two networks, implying that the actors that transfer knowledge under this relationship form densely connected cliques, permitting the fast diffusion of knowledge in the most distant parts of the network. The higher average shortest path of the Entire *Coordination* Network, on the other hand, confirms the existence of hubs inside the network, closely connected between them; then, knowledge has to pass a series of hubs in order to reach the distant parts of the network.

At the micro-level, the Entire *Collaboration* Network (Table a1, Appendix) is dominated, in terms of degree centrality, by a core of tightly connected local actors, among which the most important one is the local university followed by the two biggest local research centers and the public agency of the province. There is also the contribution of international universities and the National Research Council. However, in terms of coordination (Table b1, Appendix) the knowledge network is dominated almost exclusively by local actors. In this core appear as well the local innovation hubs and local large firms. This shows that an amount of knowledge in Trentino is managed also by the local actors despite their fact that some of them acquire smaller number of relationships than other national or international actors. The main coordinators are the local university, the biggest research center and the province, turning themselves to knowledge storages on ICT sector. Although there are few funding actors (Table c1, Appendix) and the majority of funds are coming from the European Union, the second bigger funding entity is the province, with smaller fund inflows by the national government of Italy, international research centers, and industrial associations. The actors benefitted by these funds (Table c2 , Appendix), either international or national and local, are the local university, research centers, public agencies, but also large firms and innovation hubs. This comparison represents the routes of knowledge inflows and outflows of knowledge in the field of ICT. There is a big inflow of funds and knowledge from mainly European sources, which are distributed by the local actors to high and low connected actors inside and outside the region (local-buzz and pipelines).

In terms of betweeness centrality, in all three networks created by collaboration, coordination, and funding relationships the dominant actors are local. In the Entire *Collaboration* and *Coordination* Networks (Tables a2 and b2, Appendix), the highest score is achieved by the local university, followed by the local research centers and the province. The local university acts as a broker inside the knowledge network linking together the different projects, transferring knowledge in different parts of the network, and managing the distribution of knowledge among the rest of the actors of the network. The image is slightly different in the Entire *Funding* Network (Table c3, Appendix), where the role of broker is taken by the province and the local innovation hubs. Consequently these entities act as supervisor of the funds (and knowledge) allocation for fostering the knowledge production and innovation process. Comparing the betweeness centralities of the actors in the three cases, it is obvious that the knowledge intensive institutions are the gate keepers of knowledge, while the local government and innovation hubs have mostly a supportive role in this process.

The closeness centrality in the Entire *Collaboration* Network is balanced between local, national, and international actors (Table a3, Appendix). The same tightly knit core of local actors seems to be more close to all the other actors of the knowledge network, with highest score to be achieved by the local university. This means that the local university can reach more easily the knowledge produced in the periphery of the network. Also in the Entire Coordination Network, the closeness centrality is balanced among local, national, and international actors (Table b3, Appendix). In this case in the central core of local actors, also the innovation hubs of the region are included. So, although they are not participating actively in the knowledge production and transfer, they are managing it in order to reach the peripheral actors of the network that can be the local SMEs or recent entries in the system that have not so many connections. In the Entire Funding Network, except of the high scores of the local university and the biggest local research center, the dominant actors are mostly national and international funding entities (Table c4, Appendix). The role of these funding entities is the monitoring of the funded actors, so that their funds reach the peripheral actors of the network.

The last measure of the micro analysis of the entire knowledge network level is the eigenvector centrality. This measure calculates the centrality of actors in terms of its relationships with other central actors. In other words, it introduces the value of ties characterizing each actor. In the Entire *Collaboration* and *Funding* Networks the most important actor is the local university, as far as the number of interactions with all the central actors of the network is concerned (Tables a4 and c5, Appendix). In the Entire *Collaboration* Network, the high-scores are balanced among local, national, and international actors (Table a4, Appendix). The dominant local university is followed by the biggest regional research center and the province, but also by key national and foreign research centers. So, the strategic collaborations are mainly achieved by the knowledge intensive institutions of the region in the field of ICT. In the Entire *Coordination* Network the dominant actor is the province and its tool system (Informatica Trentina) (Table b4, Appendix). So, the local government achieves strategic coordination positions in the network by managing the knowledge circulated to important coordinators and from them to the peripheral nodes. This network is dominated by the local actors. Except of the province, the local university and the biggest research center, the main regional public agencies and innovation hubs are playing key roles in creating important relationships. Also in the Entire *Funding* Network, the local actors (university, research centers, and key public agencies) achieve high eigenvector centrality scores (Table c5, Appendix). This means that these entities are connected with the most funded entities of the RIS and directly with the main providers of funds.

Table 4: Overall knowledge network measurements for the local Trentino ICT collaboration, coordination, and funding networks

	Local Collaboration Network	Local Coordination Network	Local Funding Network
Nodes	157 (6 isolates)	157 (17 isolates)	157 (41 isolates)
Edges	946	223	151
Average Degree	12.051	2.841	0.962
Average Weighted Degree	21.389	6.013	2.522
Network Diameter	4	5	4
Graph Density	0.077	0.018	0.012
Network Centralization	0.564	0.429	0.895
Average Clustering Coefficient	0.876	0.685	0.058
Average Shortest Path Length	2.198	2.713	1.975

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

Table 4 presents the overall measurements for the relationships that produce the collaboration, coordination, and funding network for the second local level of analysis (i.e. the local network). In this level the local (Trentino) actors and the relationships between them were isolated (Figures 21a, 21b, 21c, the figures in full page format can be found in the Appendix). The number of the local actors participating in collaborative ICT projects is 157. In all the three local networks appear some isolate actors, indicating the collaboration, coordination and funding of these actors exclusively with and by actors external to the region. In the Local *Collaboration* network (Figure 21a) the isolates constitute only the 4 percent of the local actors, and they are exclusively SMEs and research centers. These actors throughout the last fifteen years collaborated exclusively with national or international partners. In the Local *Coordination* network (Figure 21b) the amount of isolates increase to the 11 percent of the number of local actors. This indicates that some actors are either members of projects coordinated by external actors or coordinators in projects with exclusively external participants. Hence, there are flows of knowledge from and towards Trentino innovation system that are not diffused to the rest of the actors, when an actor is not connected to the rest of the network by another type of interaction. The amount of isolates increases to 26 percent for the Local *Funding* network (Figure 21c), showing that one quarter of the network completely depends on funds external to the region. However, the rest of the actors are supported by local funding entities, so they can be included in the knowledge creation process.

The relationships between the local actors can describe the knowledge spillovers inside Trentino. The weighted average degree for all the networks is at least double than the average degree. In the Local *Collaboration* Network, this implies the existence of repeated collaborations between the actors of the RIS. In the Local *Coordination* Network the average weighted degree is almost tripled, providing evidence on the existence of collaborative ICT projects powered locally. In these projects the knowledge produced is circulated repeatedly by the local coordinators; so, although they are coordinating only a small number of local actors, they are doing it repeatedly through time. In the Local *Funding* Network, the average weighted degree is again double than the average degree. The fact that the average degree is lower than 1, proves the existence of actors financed only by national and international sources. The average weighted degree shows the presence of a funding actor in the local network financing a group of local actors. Comparing the three networks, the presence of a smaller local core inside the RIS knowledge network that manages the knowledge generation and creation inside the region is evident. The high percentage of local SMEs in the local networks shows that in this way the local knowledge network includes in the innovation process actors that in other case would not be included.

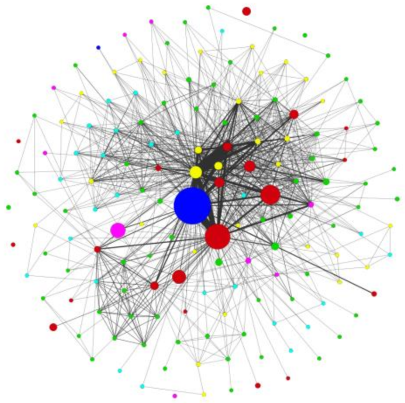

Figure 21a: Local Trentino ICT Collaboration Network

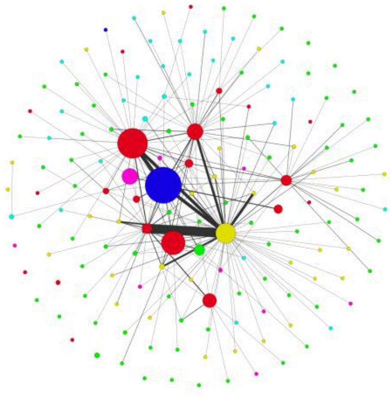

Figure 21b: Local Trentino ICT Coordination Network

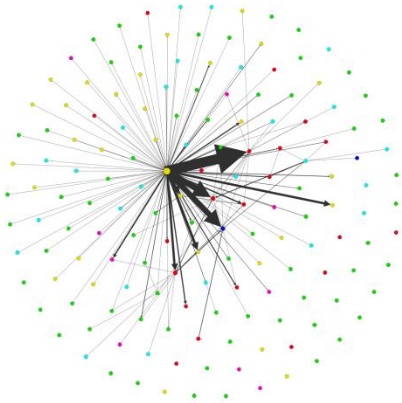

Figure 21c: Local Trentino ICT Funding Network

The diameter of the network in all three abovementioned cases is quite small, and then the knowledge can be diffused easily to the local actors. These three networks are quite sparse as the knowledge is diffused in all the three cases by the tightly knit core of local key players to the peripheral nodes. This is confirmed by the network centralization, whose value is medium for both the Local *Collaboration* and *Coordination* Networks. The knowledge is transferred to the local actors through projects powered by different local participants. However, the high degree centralization of the funding network points out the presence of a main local funding entity. The fact that this measure is not equal to one shows the existence of smaller funding entities located in the region. The clustering coefficient of the Local *Collaboration* Network is rather high due to the underlying structure of the network in projects. So, the knowledge can be easily transferred from one part of the network to the other through few intermediate actors. The clustering coefficient of the Local *Coordination* Network is medium showing the exchanging of the local actors in the role of project coordinator. In the Local *Funding* Network the clustering coefficient appears significantly lower and the funds are directed to straight from the funding entity to the funded actors. In this network there is a few percent of actors funded by local sources, while the majority is participating in the innovation process with the help of national or international funds. The average shortest path length appears to be small for all the three networks, which allows knowledge and funds to reach quickly the parts of the network that are connected with the core of key actors.

At the micro level, the province is the dominant actor, in terms of degree centrality, in the knowledge transfer network inside the region of Trentino. At the local level the province plays the most significant role in the creation and diffusion of knowledge, instead of the university (like in the case of the entire knowledge network). This indicates that the knowledge produced inside the region and transferred between local actors is mainly managed by the local government. Apart from the province, in the Local *Collaboration* network, the university and a group of research centers and public agencies play a significant role in the knowledge diffusion (Table d1, Appendix). So, the amount of knowledge produced from local collaborations is supported and fueled by the knowledge intensive institutions and public bodies. This could suggest that the knowledge produced inside Trentino is applied in innovations introduced by the local institutions. In this procedure the participation of local large firms is rather low, which could lead to the export of all the theoretical knowledge outside the borders of the region. The high score of degree centrality of the PAT in the Local Coordination network (Table e1, Appendix) demonstrates that the knowledge in the local network is mainly managed by the province and its tool system (Informatica Trentina), distributed to the rest of the key actors: the local university, the local research centers, the innovation hubs, and some central public agencies. From there the knowledge is redistributed to the rest of the local actors. Finally, the main fund provider in the Local *Funding* network (Table f1, Appendix) is the province itself, followed by several private and public local funders, whose contribution is however considerably smaller. The actors mostly benefited by these local funds (Table f2, Appendix) are the tool system of Trentino's public administration, the local university, the biggest research center, and a series of smaller local research centers and public agencies. Consequently, in the local knowledge network knowledge is following a hierarchical route in order to include the local peripheral actors to the innovation process, while funds are distributed directly to the participants by the central funding entity.

In terms of betweeness centrality, the main knowledge gatekeeper in the local level of analysis is again the local government. It appears to connect the different parts of the local networks that in different case would be isolated. In the case of Local *Collaboration* network (Table d2, Appendix), other brokers than the province are the knowledge intensive institutions of the region, with leading ones the university and the biggest research center. Brokering role appears to be played also by the innovation hubs inside Trentino. The same appears to happen in the Local *Coordination* network (Table e2, Appendix), even if the role of manager of local knowledge is minor for the university of Trento. The knowledge intensive institutions in the region guarantee the knowledge transfer in terms of expertise. In the Local *Funding* network (Table f3, Appendix), the most important broker is the province, with all the rest of the actors to be rather less significant. The local government is the main administrator of funds/knowledge, connecting the different funding sources between them and allowing the less connected actors to have access to funds.

Considering the closeness centrality, in the Local *Collaboration* and Local *Coordination* networks the key role is kept by the province (Tables d3 and e3, Appendix). The province is the main actor including the most peripheral local actors into the knowledge production and diffusion process. It is close to these actors in order to absorb the knowledge produced by them, while providing them with knowledge produced by the knowledge intensive institutions of the region. The role of the province is to support the less connected actors of the region, like the local SMEs or new entrants to the system, by including them in collaborative projects and coordinating them effectively. In the Local *Funding* network (Table f4, Appendix), the picture changes with the local university distributing funds, and consequently knowledge to these peripheral actors. In all the three network, the role of innovation hubs appears to be limited and their influence quite restricted, while in terms of knowledge distribution and management they are substituted by the key public agencies.

Finally, in terms of eigenvector centrality, the Local *Collaboration* and Local *Coordination* networks (Tables d4 and e4, Appendix) are dominated by the province and its tool system (Informatica Trentina). This means that these two actors are connected with all the important actors of the region in order to accumulate knowledge and know-how that foster both the innovation process and its management through coordinating projects. High eigenvector centrality scores, however less high that the score of province, are achieved by the local university, the research centers and key public agencies, being connected with the most important actors in the region. In the Local *Funding* network (Table f5, Appendix), the knowledge intensive institutions of the region achieve higher scores as they are connected with the main funding entities, assuring with their expertise that the funds will not be wasted.

From the horizontal analysis of the two first levels, it is obvious that the key actors in the region are three, connected to a tightly knit core. These anchor actors are the province, the local university, and the biggest local research center. Isolating these three anchors, their role inside the knowledge network of the RIS becomes clearer, and their strengths and weaknesses can be identified. Tables 5, 6, and 7 show the descriptive measurements of each one of them and their role in the knowledge flows through collaboration, coordination, and funding activities.

Table 5: Collaboration Ego-networks of the anchor actors of Trentino knowledge network (local university, biggest local research center, and local government)

		Local University	Biggest Local Research Center	Local Government
Number of nodes (percentage of the entire network)		949 (39.64%)	616 (25.73%)	245 (10.23%)
Number of edges (percentage of the entire network)		18574 (40.25%)	9076 (19.67%)	2238 (4.85%)
Partition of nodes according to their position in percentages	**Local**	7.8%	12.82%	39.59%
	National	16.33%	16.23%	29.8%
	International	75.87%	70.94%	30.61%
Partition of nodes according to their organizational kind in percentages	**Universities**	30.35%	22.4%	12.24%
	Research Centers	23.18%	21.27%	15.51%
	Large Firms	18.44%	22.56%	13.06%
	SMEs	18.97%	22.74%	26.12%
	Public Agencies	4.64%	6.17%	23.27%
	Other	4.43%	4.87%	9.8%

The statistical analysis was performed with Gephi (Bastian et al, 2009)

Table 5 presents the descriptive measures of the collaboration ego-network of the anchor actors of the Trentino knowledge network. The ego-networks were isolated for each anchor separately from the entire Trentino *Collaboratio*n network (Figures 22a, 22b, and 22c, the figures in full page format can be found in Appendix). These three key actors of Trentino knowledge network, when isolated, are connected with a wide part of the network. The local university alone is connected with the 40 percent of the entire Trentino knowledge network. Looking at the partition of the nodes connected with the local university and the biggest research center according to their location, a similar division is observed. These two key actors are mostly connected with international organizations (more than 70 percent), constituting pivotal actors to the connectivity of the region with other distant regions. They import knowledge into the region by participating to projects with organizations based outside the Italian borders, while in the same way they export the know-how created inside the region. They are respectively connected with a number of national actors (around 16 percent), however, it can be considered a small amount compared to their international connections. Considerably small is the number of their local connections, with those of the local university to be less than 10 percent of its ego-network. The ego-network of the local governmental body (province) appears to be more balanced respecting the location of the nodes connected to it, with equal percentages of local, national, and international connections.

Consequently, it is the province that includes the local actors to the knowledge generation and transfer, fostering the knowledge flows inside the region.

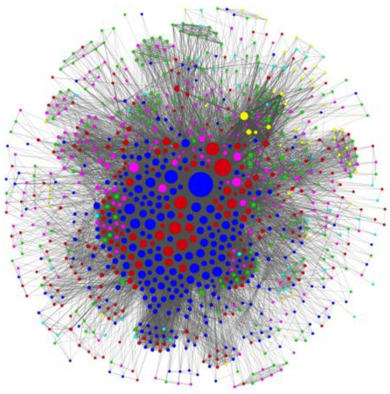

Figure 22a: Collaboration Ego-Network of the Local University in Trentino

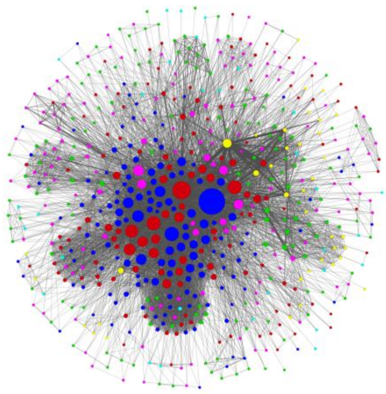

Figure 22b: Collaboration Ego-Network of the Biggest Research Center in Trentino

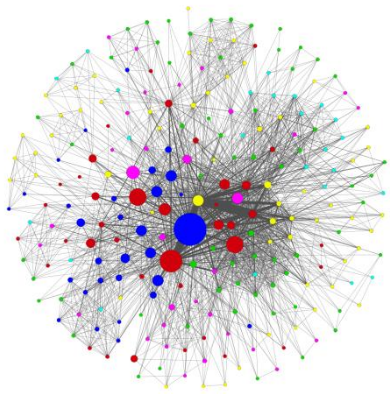

Figure 22c: Collaboration Ego-Network of the Local Government body in Trentino

In terms of the partition of the nodes according to their organizational kind (Table 5), the local university is significantly more connected to other national and international universities than the other two anchors. In general, it is connected with other knowledge intensive institutions mostly (the 50 percent of the connected actors), while it has a medium connectivity private actors, large firms and SMEs, and rather low connectivity with public agencies. This gives a hint about the preference of the local university to cooperate with other universities and research centers. In this kind of partition, the connections of the biggest local research center appear to be more balanced among knowledge intensive institutions and private actors. The augmented percentage of connections with large firms and SMEs, leads to the conclusion that the knowledge produced by these projects targets to production of new products and services. Again, rather small is the percentage of connection with public agencies. Finally, the local government is mostly connected with other public agencies and SMEs, introducing the less connected and peripheral actors to the knowledge production and transfer, and consequently to the regional innovation process.

Table 6: Coordination Ego-networks of the anchor actors of Trentino knowledge network (local university, biggest local research center, and local government)

		Local University	Biggest Local Research Center	Local Government
Number of nodes (percentage of the entire network)		202 (8.44%)	164 (6.85%)	102 (4.26%)
Number of edges (percentage of the entire network)		600 (14.67%)	407 (9.95%)	197 (4.82%)
Partition of nodes according to their position in percentages	**Local**	10.4%	23.17%	61.76%
	National	19.31%	20.12%	30.39%
	International	70.3%	56.71%	7.84%
Partition of nodes according to their organizational kind in percentages	**Universities**	36.14%	24.39%	6.86%
	Research Centers	25.25%	23.17%	15.69%
	Large Firms	20.3%	26.22%	12.75%
	SMEs	11.88%	13.41%	26.47%
	Public Agencies	2.97%	6.71%	30.39%
	Other	3.47%	6.1%	7.84%

The statistical analysis was performed with Gephi (Bastian et al, 2009)

Table 6 presents the descriptive statistics of the coordination ego-networks of the three key actors of Trentino knowledge network: the local university, the biggest local research center and the local governmental body (Figures 23a, 23b and 23c, full page format of these figures can be found at Appendix). Although in terms of collaboration these three actors are connected to a big part of the network, in terms of coordination their connections are rather few (maximum 15 percent of the entire coordination network). This indicates that the majority of knowledge produced by projects with either national or international actors is managed outside the borders of the region. In the projects coordinated by the local university the majority of connections are again international (70 percent), while a 20 percent of them are national, leaving only a small share of coordinating projects with local participants (10 percent). The local university, consequently, constitutes an important player at the international level that is able to export the knowledge produced inside the region or import knowledge from abroad. The biggest local research center seems to be a rather important international player (57 percent of the connections), however it participates more in regional projects and regional knowledge creation and diffusion (23 percent), coordinating an amount of projects with local participants. Finally, although the local governmental body manages the smallest part of the knowledge flows inside Trentino, this anchor is the most connected one to the local actors (62 percent), guaranteeing the smooth flow of knowledge inside the region. Its role is also important at the national level, as it coordinates an amount of projects with national participants (30 percent). Its connectivity in terms of project coordination outside Italy appears rather limited.

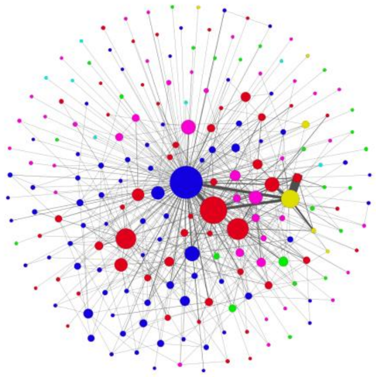

Figure 23a: Coordination Ego-Network of the Local University in Trentino

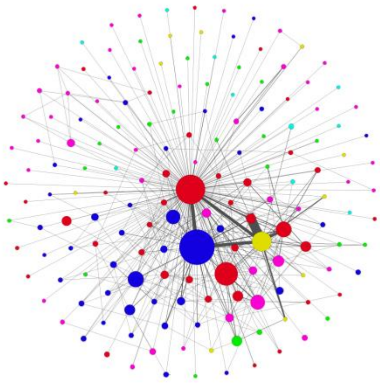

Figure 23b: Coordination Ego-Network of the Biggest Local Research Center in Trentino

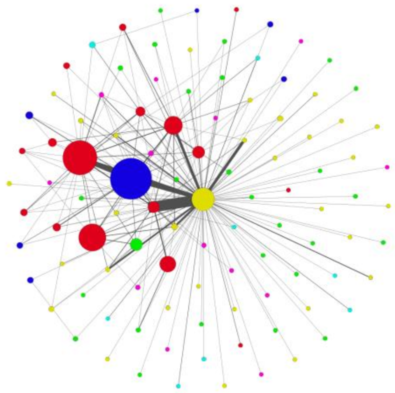

Figure 23c: Coordination Ego-Network of the Local Government Body in Trentino

Classifying the number of connections of these three anchors according to their organizational kind (Table 6), their role inside the entire coordination network appears highly diversified. The university has higher connectivity in terms of project coordination with other universities and research centers (together more than 60 percent). Consequently, it coordinates projects where the participants are knowledge intensive institutions, mainly national and international. This results to the accumulation of knowledge by the local university, a key player at both the national and international levels. An important share of connections are also those with the large firms (20 percent). Being coordinator in such projects, the local university becomes a hub of know-how in the ICT field, guaranteeing the knowledge transfer with its expertise. At the same time, the shares of SMEs and public agencies are significantly lower. The biggest research center demonstrates a more balanced distribution of coordination interactions. Its connectivity by project coordination is equally distributed between universities, research centers and large firms (about 25 percent each). Compared with the local university, also the share of connections with SMEs is higher. This means that the objective of the research center is to coordinate more applied and close-to-market research projects. Finally, the local government mostly coordinates the local or national SMEs and public agencies (56 percent together). The inclusion of the SMEs in the knowledge transfer process makes the local government a trustworthy entity in terms of knowledge coordination inside the region.

Table 7: Funding Ego-networks of the anchor actors of Trentino knowledge network (local university, biggest local research center, local government)

		Local University	Biggest Local Research Center	Local Government
Number of nodes (percentage of the entire network)		20 (0.84%)	33 (1.38%)	177 (7.39%)
Number of edges (percentage of the entire network)		67 (2.47%)	96 (3.53%)	328 (12.07%)
Partition of nodes according to their position in percentages	**Local**	45%	24.24%	57.06%
	National	30%	30.3%	30.51%
	International	25%	45.45%	12.43%
Partition of nodes according to their organizational kind in percentages	**Universities**	10%	12.12%	10.17%
	Research Centers	35%	24.24%	16.38%
	Large Firms	15%	21.21%	9.6%
	SMEs	5%	12.12%	29.94%
	Public Agencies	15%	12.12%	19.77%
	Other	20%	18.18%	14.12%

The statistical analysis was performed with Gephi (Bastian et al, 2009)

Table 7 presents the funding ego-networks of the anchor actors. The local university and the biggest local research center, as it is obvious also in the figures 23a and 23b (full page format of the figures can be found in the Appendix), are almost exclusively funded by a small set of funders by repeated funding relationships. They constitute a rather small part of the entire funding network. The only key actor presenting funding activity is the local government (12 percent of the entire funding network). This shows that the province plays a substantial role to the support of the knowledge transfer at the local level (Figure 23c), even if the majority of funds comes from external sources (like the European Commission or the Italian government). Even if the local university and the biggest local research center are not important actors for the funding network of the region, they are quite strong in acquiring funds and consequently knowledge from sources external to the region. The funders of these two institutions are equally distributed in terms of location. The local government as a funding entity funds mostly local actors, while it receives funds from other sources. This makes the province the main supportive actor inside the region; without its contribution a big part of the local network would be left out from the knowledge transfer process.

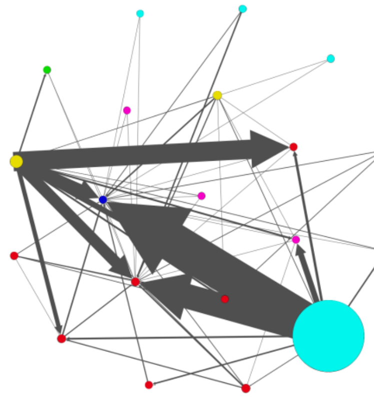

Figure 24a: Funding Ego-Network of the Local University in Trentino

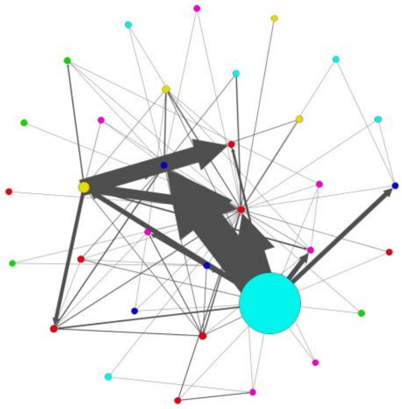

Figure 24b: Funding Ego-Network of the Biggest Research Center in Trentino

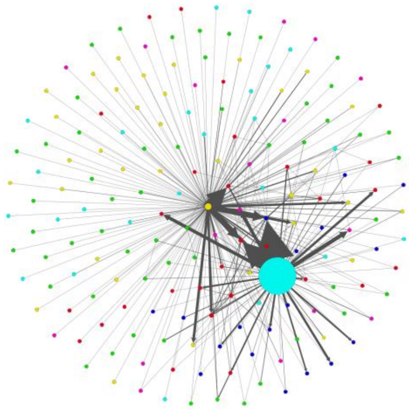

Figure 24c: Funding Ego-Network of the Local Government body in Trentino

The local university and the biggest local research center are funded from several kinds of organizations inside and outside the region. An important role in their funding is played by supra-national institutions like the European Union, National ministries, but also by large firms and associations investing in the region. On the other hand, the regional funds, managed by the local government, are mostly invested on SMEs, other public agencies, and smaller research centers. The province in this way creates a mechanism of inclusion for the smaller actors into the innovation process, which otherwise would be excluded and isolated. So, its role is to guarantee access to funds and knowledge for the less connected regional actors.

In terms of network resilience, these three anchors are tightly connected among them in a core around which the rest of the regional collaboration network is developed. So, even if one of them is missing no isolate actors are produced. For a big amount of projects at least two of these anchors are included in among the participants, so in case of a lack of one of them, the knowledge continues to flow inside the Trentino collaboration network without particular obstacles. However, this is not the case for the coordination network of knowledge in Trentino. In the coordination network of ICT activity in Trentino, if one of these three actors disappears, big part of the network becomes isolated. This implies, as consequence, the absence of entities managing the knowledge transfer inside the region, so that the peripheral actors have no access to knowledge resources. If the local university disappears, the actors mostly affected are other universities external to the region and research centers. Thus, the mechanism that is mostly affected is the transfer of knowledge from and towards contexts external to the region, having as a consequence a probable isolation of the region in terms of knowledge on the field of ICT from the national and international contexts. When the biggest research center is extracted from the network, mostly private actors (large firms and

SMEs) become isolated. This means that the region becomes significantly less connected with the applied research in the field of ICT. The theoretical knowledge will be distant from the actors that can exploit it and transform it to products and services. If the local government disappears, though, the actors mostly affected are the local SMEs and public agencies. So, when the actor fostering the local interaction disappears, the internal production of knowledge in the field of ICT will be reduced and actors more peripheral in the ICT knowledge production and transfer will be isolated.

As mentioned above the three anchor actors of the Trentino ICT knowledge network are closely connected in terms of collaboration ties. All together their connections constitute more than the 50 percent of the entire network, making this core of actors significantly important for the smooth transfer of knowledge to all the parts of the network. However, what happens if all these three actors disappear with all their connections and the know-how they have accumulated the last fifteen years? The underlying structure of the network in projects, helps the network not to collapse, as actors connected by a small world topology are sharing the knowledge produced from every project. However, a 10 percent of the network becomes isolated, a percentage that cannot be considered small. These actors, mostly local SMEs and research centers, are excluded from the knowledge transfer process and consequently from the innovation production in the field of ICT.

Following the same procedure and extracting from the network the core of anchors, for the coordination and funding networks, even more relevant issues arise. In the coordination network the combined ego-networks of the anchor actors constitute a 20 percent of the entire coordination network. This means that the coordination of the main body of knowledge is done outside the borders of Trentino. However, the effect of the loss of these actors appears to be slightly bigger than the collaboration one. A 15 percent of actors of the entire network become isolated in terms of coordination. Among them, apart from the local less benefitted actors, are international actors, like universities and research centers. Considering the projects in which these anchors are coordinators, with their absence around the 40 percent of the network becomes isolated. This fact makes these actors important for the amount of knowledge they administrate.

The funding ego-networks of the three anchor actors represent a rather small part of the entire funding network (hardly the 10 percent). However, for the support of local innovation activity, it is substantial, mainly due to the funding activity of the province. The biggest part of the funding comes to the region from external sources like the European Commission, however with the absence of these three key actors and mainly of the local government, a big amount of local actors remain without financial support, which prevents them from being involved in the regional process of knowledge creation and diffusion. These local actors are directly depending on the province for access to knowledge and funds, which makes province an indispensable element of the regional knowledge network, due to its supportive role.

5.5 Conclusions

As discussed in this chapter, according to the classification of Cooke (2001), Trentino fulfills the criteria to be considered as a high potential RIS. It is characterized by autonomous spending and (partly) taxing, as the regional government decides the actors to which it should allocate funds. Furthermore, it designs special policies to support regional innovation. Another reason is the possibility for the regional government to directly administrate the infrastructures of different kinds, like transports, telecommunications, universities, research centers, incubators and so on. Also at the superstructural level, there are several evidence of the high potential of Trentino, like the cooperative culture characterizing the region, the externalization and interactive innovation in the organizational level of the actors of the RIS, and the inclusive, monitoring, and networking attitude of the regional governance.

The ICT field is a part of the entire innovative activity in the Trentino RIS. Nevertheless, given the amount of investment of the regional government in the last fifteen years, it can be considered an important field of the innovative activity and of the regional economy. Essential for the development of the ICT activity in the region is the development of the network of knowledge in this field. The analysis of the knowledge flows and spillovers inside the region is crucial for giving a complete idea of how this network functions, and what is needed to be taken into consideration by the regional policy makers. The identification of the key actors of the knowledge network in an innovative field is essential for understanding their role in the innovation process and in general inside the complete RIS.

According to the analysis of the previous section (section 5.3), the actors cooperate between them in order to diffuse knowledge in two ways: either they repeat previous collaborations or they trust actors with common characteristics to them (proximity). Then, the actors of Trentino either reinforce the existing trust with repeated collaborations or they target to distant actors with certain characteristics and by cooperation with them the trust follows (Fitjar & Rodrigez-Pose, 2014). Knowledge flows inside the network through the interactions created by the collaborative projects. This underlying structure of the interactions for knowledge creation and diffusion enables the diffusion of knowledge in the most peripheral parts of the network, while it does not allow interruptions in the flow of knowledge inside the region. A big part of the knowledge produced by the collaborative projects is managed outside the region. However, the part of the knowledge managed by regional actors is shared to the key actors of Trentino, so discontinuities in knowledge flows because of knowledge management are difficult to happen as well. The funds in the region are coming from a small number of funding entities, with the majority of them to be European funds.

More specifically, the entire Trentino knowledge network is dominated by a core of tightly knit actors. In the process of knowledge diffusion however, national and international institutions are playing an important role by having repeated collaborations with the local actors. These are the global pipelines created by the participation of the local actors in collaborative projects of national and international scale (Bathelt et al, 2004). The knowledge produced by all the innovative activity of the region is coordinated both internally and externally. The local actors are in a big number of cases simple participants in the collaborative projects, although there is a big part of knowledge managed inside Trentino.

Trentino actors play other two roles in the entire knowledge network of the region in the ICT field; the role of brokers and strategic collaborators. The local actors are those connecting different parts of the knowledge network, while the regional knowledge intensive institutions constitute the main gatekeepers of knowledge transfer. The same knowledge intensive institutions are those achieving the most strategic collaborations in the entire knowledge network. In general, the local actors are connected with the most funded entities of the knowledge network and directly with the main fund providers, which gives them easy access to knowledge and funds.

Talking about the funding activity in the entire Trentino knowledge network, the main funding entity is the European Commission, followed by smaller funders like the province or industrial associations. There is a big inflow of funds that are managed by the local actors, distributed to high and low connection actors inside and outside the region, while the role of national and international funding entities is the surveillance of the destination of their funds.

A quite significant part of knowledge is generated exclusively inside Trentino and diffused between the local actors. This is the so-called local buzz, from which are benefited the regional actors by the colocation (Bathelt et al, 2004). So, the local actors tend to repeat co-operations between them due to this colocation, choosing their partners in collaborative projects in the criterion of trust developed by geographical proximity. However, in terms of collaboration and coordination of knowledge, there are actors inside the region that prefer to collaborate exclusively with external to the region actors. In case that there is no other official or unofficial relationship to connect these actors with the local system, the knowledge imported cannot be diffused to the rest of the RIS. Despite this, the presence of such actors in the region indicates that they have benefits from the collocation with other knowledge intensive actors.

The knowledge in the local network can be diffused easily to the local actors, so there is a high participation in the knowledge network of the local SMEs and other actors that otherwise would not be included to this process. Again at the local level, the knowledge is diffused by the same tightly knit core of local key players through projects powered by different local participants. This knowledge can be easily transferred from one part of the network to another through few intermediate actors and by a structured route, in order to reach the peripheral actors of the region. It is directed from the main actors to the key actors/hubs and then redirected to the rest more peripheral local actors.

In the local funding network can be observed a lot of isolate local actors. These are the actors that are financed exclusively from national and international sources. The rest of the local actors are financed by a main local funding entity, while there are smaller funding entities located in the region. These funders finance directly the actors, so they ensure their participation to the knowledge network of Trentino. In this way knowledge and funds reach quickly all the parts of the regional network.

Taking a closer look to both the entire knowledge network of Trentino, a tightly connected core of three key institutions is distinguishable. These are two knowledge intensive institutions, the local university and the biggest research center of the region, and the local government. The role of these three anchors appears to be indispensable, while the rest of the organizations in the region are benefited by their presence in terms of knowledge.

Among the local actors, the university dominates the entire network, transferring the knowledge through its interactions and reinforcing the innovation activity of the region. It creates the most strategic connections with important external actors transferring to the regional network external knowledge and funds. With its expertise guarantee the knowledge transfer in different parts of the local knowledge network, including the most peripheral actors. In the same time it is strongly connected to the main funders assuring that their funds are not wasted. So, it constitutes a pivotal actor that connects Trentino with the rest of the world, collaborating mostly with national and international universities and research centers. Being a key player in national and international levels, the local university accumulates knowledge from external to the region knowledge intensive institutions, while through its connectivity inside the region diffuses this knowledge to the rest of the local actors. In terms of funding, it is connected to all the important funding entities, while it brings to the region important flows of funds by international sources. Its absence could possibly lead to the isolation of the region from the external sources of knowledge and consequently would harm the ability of the region to create global pipelines.

Similar is the role of the biggest local research center. It also constitutes a gatekeeper of knowledge imported to the region from distant regions and markets. It constitutes as well a pivotal anchor for the region, being funded from regional, national and international sources, however, it appears more involved to the regional knowledge network than the local university in terms of knowledge management. It is an international knowledge coordinator and in the same time is more engaged to the coordination of collaborative projects powered by the region. It also collaborates more than the other two actors with private actors, so the target of the knowledge production is the creation of innovative products and services. Its absence could possibly isolate the knowledge produced by the region from the market oriented institutions that rely on the expertise of this research center for the production of applied knowledge in the field of ICT.

Even more crucial appears to be the role of the local governmental body, the province. It is the main funding entity of the region and the main regional knowledge gatekeeper, while in the creation of external linkages it has mostly supportive role. It also supervises the allocation of funds and knowledge to the local ICT actors. In terms of managing the incoming knowledge, it achieves strategic coordination positions inside the network that allows it to circulate the imported knowledge to key coordinators and from them to more peripheral nodes. In the local knowledge network, it allocates the funds directly to the majority of local actors, especially the less benefited, in order to include them to the knowledge production and transfer process. In this way it connects different parts of the local network which otherwise would be isolated. It is also connected with all knowledge intensive actors in the region, accumulating know-how and being point of reference for the local system.

The local governmental body collaborates mostly with SMEs and public agencies introducing and including them to the knowledge production and transfer. Its importance it is obvious as it manages the regional knowledge and it is considered a point of reference in regional and national levels, while its connectivity outside Italy is limited. Its funding role is significant for the continuity of the knowledge transfer inside the region, as it funds the local SMEs and public agencies, securing and guaranteeing access to funds and knowledge to the less connected local actors. Its absence would cost to the regional knowledge network the interruption of almost all the regional knowledge production and activity in the field of ICT, leaving a big part of the network isolated.

From the analysis it appears that the local initiative created in a span of fifteen years a solid network of knowledge transfer in the field of ICT in the region of Trentino. The knowledge network is difficult to collapse with the malfunction of one of its actors due to its structure in projects. However, there are some points where the local policy makers should take attention to. The region should attract more private investments in the field of ICT as it is the public rather than the private sector that drives the development of the knowledge network in the region. Also the intense participation of the foreign actors in the wider knowledge network indicates that there is space for more cooperation between the local actors. In this way the local government should promote the collaboration of less connected local actors with the more central ones in the knowledge network. Although the province does not play a key role in the entire knowledge network its support in terms of funds it is significant for including the least favored actors to the knowledge generation and transfer process.

In many cases the province also substitutes the low participation of the local innovation hubs to the knowledge network. This can be a point of concern for the local policy makers. The innovation hubs are not participating actively in the knowledge production and transfer, but they manage this knowledge in order to reach the peripheral actors of the network that can be the local SMEs or recent entries in the system without a lot of connections. However, their connectivity to the national and international actors is limited, so they cannot import or export knowledge from within and towards the regional actors by creating pipelines with distant regions. So, their role is limited and even in the regional level they are substituted in several cases by either the province itself or by some key public agencies.

CHAPTER 6

KNOWLEDGE NETWORKS AND STRONG TIE CREATION: WHAT IS THE ROLE OF THE PROXIMITY?

In addition to the policy implications at the local level that the present research has, it can also contribute with valuable insights in the evolution of knowledge networks of emerging RIS. A key concern in the international literature is how the agents in a regional knowledge network choose other agents for the creation and transfer of knowledge. One of the criteria for their choice is the similarity in the attributes of actors, the so-called proximity in the innovation literature (Borgatti & Foster, 2003; Asheim & Isaksen, 2002; Inkpen & Tsang, 2005; Boschma, 2005). The scholars argue in the definition and the dimensions of proximity, however they all agree that proximity is needed in some (although not necessarily all) of its dimensions for connecting the actors of an RIS and enabling the knowledge flows and innovation (Boschma & Frenken, 2010).

In the majority of the literature, the term proximity refers mostly to geographical proximity. However, two actors in the knowledge network can be proximate even if they are not geographically close. So, different kinds of proximity exist that can be classified in different categories. The most popular classification is the one of Boschma (2005) who proposed five dimensions of proximity that affect the propensity of actors to exchange knowledge and innovate, analyzed extensively in the literature review section (Chapter 2). The present research examines four kinds of proximity; geographical, institutional, organizational, and relational.

Geographical proximity is the physical distance of two actors. It plays a significant role in facilitating the other kinds of proximity. However, geographical proximity can directly affect the probability that two actors exchange knowledge (Broekel & Binder, 2007). It is strongly claimed by the literature that geographical proximity is the initial reason for the formation of relationships and networks, as close geographical distance is implying a lot of interaction between co-locating actors (Hoekman et al, 2009). In the present research as actors geographically proximate are defined those who co-locate inside the borders of the region under investigation which are consequently the borders of the RIS.

Institutional proximity is the aspect of proximity where the actors share common institutional and cultural attributes. It can be expressed by either formal institutions, such as laws, or informal institutions, such as cultural norms, providing to the actors stable conditions for knowledge transfer (Boschma & Frenken, 2010). Further, common language, shared habits, a common law system etc., secure a basis for coordination and interactive learning (Maskell & Malmberg, 1999). Thus, the present research deals with institutional proximity, considering two actors as proximate when they are based in the same national borders.

Organizational proximity is the degree of similarity of actors in organizational terms. Organizational proximity is believed to help the knowledge exchange and reduce the transaction costs. The definition of organizational proximity which the present research uses is the one of Metcalfe (1994), according to which organizations are close in terms of routines and incentive mechanisms. Usually, in innovation studies, there is a distinction between profit and non-profit organizations, or private and public. However, in the present research, there is a more detailed distinction in terms of incentives and orientation of the organizations. So, the present research divided the actors in universities, research centers, large firms, SMEs, public agencies, and other kinds of organizations. The most common situation is that actors prefer to cooperate with other actors under the same organizational context. However, there are cases of organizational distance, like the 'triple helix', where actors with different organizational background prefer to cooperate with each other.

A further type of proximity used in the present research is relational proximity. Relational proximity is defined in terms of the position of an actor inside the regional knowledge network in relation with the rest of the actors. In other words, the centrality of the actor in the network is measured and compared with the centrality of other actors. The case that two actors are relationally close means that they have similarly central position in the network, while the case that they are relationally distant means that the one is more central than the other. This definition of relational proximity stems from the theory of preferential attachment, which supports that the most connected (central) nodes are more probable to receive new connections (Barabasi & Albert, 1999).

From this reasoning, several arguments are rising, while the most crucial of them is the effect of proximity on the RIS network, taking into consideration the different kinds of proximity. So, another big debate in the literature was raised about the effects of the geographical proximity and proximity in general on the RIS knowledge network (Breschi & Lissoni, 2001). Breschi and Lissoni (2009), found a limited effect of geographical proximity on the knowledge diffusion network in the field of drugs, biotechnology, and organic chemistry, while Asheim et al (2011) aim to identify the different proximity mixes that facilitate economic development within and between regions. Balland (2012) tests the effect of several kinds of proximities on the evolution of the knowledge network generated by the global navigation satellite system. This study showed the geographical, institutional, and organizational proximities favor collaborations.

The question arising is what is the effect of the proximity to the frequency of the collaborations and consequently to the creation of trust between the actors of a knowledge network. The frequency of the collaborations is expressed in the present research by the strength of the collaborative ties as it is defined by Granovetter (1973). Strong ties, or in other words the repeated collaboration between a set of actors, provides the agent with knowledge-based interorganizational trust that is deepened by the duration of the interaction and its intensity. This consequently stimulates reciprocal trust. Thus, a long duration of this mutual relationship allows the actors to accumulate knowledge and reinforce over time, thereby the tie is strengthened (Capaldo, 2007; Levin & Cross, 2004).

The present research aims to give an answer to the above concern by examining the effect of different kinds of proximity to the frequency of collaborations and the creation of trust between actors of the knowledge network of an emerging RIS. So, the main question that stems from the above argument is how the trust between actors is affected by proximity. More specifically, which kind of proximity creates more repeated collaborations and consequently more trustful interactions? Which kind of organizations inside the RIS knowledge network feel more secure to collaborate with each other? And finally, does the position of the actors in the knowledge network, central or peripheral, play a role in trust and collaboration creation? All these questions led to the creation of the following set of hypotheses (Chapter 2):

H1: The overall proximity affects positively the repeated collaboration between two actors in a regional knowledge network. In other words, the actors that are more proximate are more probable to repeat the collaboration between them.

H1a: The geographical proximity between two actors affects positively the repeated collaboration between them.

In line with the theory about the organizational proximity (Boschma, 2005; Balland (2012); Broekel & Boschma, 2012), the actors prefer to collaborate with other actors that operate under similar organizational context. In the present research the following two hypotheses are tested:

H2a: In regional knowledge networks, organizational proximity between two universities or two research centers affects positively the repeated collaboration between them.

H2b: The case when a private actor (large firm or SME) collaborates with a university or research center (actors with organizational distance) affects positively the repeated collaborations between them.

As mentioned in Chapter 2, the relational proximity in terms of position in the knowledge network should play a role in the creation of trust between actors, resulting into the following hypothesis:

H3: The relational distance in terms of degree centrality of two actors affects positively the repeated collaborations between them.

To test the above hypotheses, the data from Trentino collaborative projects on ICT was deployed, which was described in Chapter 4. The treatment of the dataset is described in the following section (6.1) in order to create a series of econometric models presented in section 6.2. In section 6.3 the results of the analysis of the models are presented, while in the last section (6.4), the conclusions stemming from the analysis of the data, the limitations, and the possible policy implications are discussed extensively.

6.1 Data and Methods

The present research uses the three kinds of network produced by the analysis of the relationships deriving from the dataset of collaborative projects on ICT field in Trentino discussed in Chapter 5 (collaboration, coordination, and funding networks). As mentioned in the discussion of the dataset in Chapter 4, the data was obtained by the lists of collaborative projects of actors that are located inside Trentino. As the initial data was structured in projects (Table 2), every project was including the participants to it, its coordinator, the funding institution and the special characteristics of each entity. So, this structure of raw data can be summarized in one two-mode and two one-mode sociomatrices (X_{pr}, X_{coor} and X_{fun}), the first where the rows are the participating actors in the projects, while the columns are the projects, the second where the rows are the participating actors, while in columns are the coordinating actors, and the third where the rows are the participating actors, while the columns are the funding entities. Concerning the first sociomatrix, in order to transform it from two-mode (actors x project) to one-mode sociomatrix (actors x actors), it is necessary to multiply X_{pr} with its transpose. In this way, the result is the adjacency matrix X_{col} which indicates the numbers of linkages between an actor x_i and another actor $x_{j.}$ For the other two matrices, this procedure is not needed as they already portray actor to actor relationships. The result of this procedure is three square matrices portraying actor to actor relationships, with the same number of rows and columns.

This chapter is aimed at answering a set of research questions, concerning the effect of the several kinds of proximity on the strength of linkages deriving from repeated cooperation in projects. The strong collaborative linkages represent the trust developed by the actors of the regional knowledge network, and consequently their preference to repeat collaborations with actors with certain attributes that inspire this trust. The term proximity in this research refers to four kinds of proximity: geographical, institutional, organizational and relational proximity, as they were defined in the previous section. Another research question that this chapter answers is: which kinds of organizations the actors prefer to repeat collaborations with, and create trustful strong relationships in case of either existence or absence of organizational proximity between the actors. For answering these questions, the possible explanatory variables of the model are discussed.

For representing the strength of ties at the end of the period under research for the ICT knowledge network of Trentino, the adjacency matrix X_{col} is used which is produced by the network of collaborative projects in Trentino in the last fifteen years. This matrix represents how intensively the actors of Trentino have collaborated in projects and constitutes the dependent variable of the model. Secondly, two independent variables were employed. These variables are the two sociomatrices that occur from the coordination and funding network respectively. The coordination sociomatrix represents the relationships where transfer of knowledge occurs through the coordinating actor of the project, assuming that the more knowledge an actor gathers from its position as coordinator in projects, the more probable is that it creates strong linkages in terms of collaboration. The funding one represents the giving or receiving funds relationships towards and from other actors in the network which can indicate exchange of knowledge as well.

For capturing the geographical, institutional, and organizational proximity, three sets of dummy variables are employed. The first checks if two actors that are located inside the region of Trentino are more probable to repeat their collaboration, controlling for geographical proximity. So, a dummy variable is employed to represent the case that two actors have high geographical proximity, in terms that they are located both inside the borders of the region.

The second dummy variable controls for the institutional proximity of the collaborating actors. Actors located in Trentino are supposed to have high institutional proximity, apart from the geographical one. However, actors that are located inside the same country are expected to have high institutional proximity as well. So, is the case of collaboration between a local and a national actor more probable to create stronger linkages? Thus, a dummy variable is employed that represents the cases in which only institutional proximity exists, in terms that one actor is located inside the region and the other actor is located in any other region of the same country. For both the aforementioned dummies, the reference is the case of international linkages (global pipelines), as a local actor can have local, national, and international connections, according to the partition of the actors described in Chapter 4. Alternatively, another notion of institutional proximity is tested. Instead of the national borders, the local actors consider institutionally proximate only the actors located in the north of Italy.

Finally, in order to control for organizational proximity, a third set of variables is employed. This set of controls checks out the cases where the actors are from the same organizational kind (for example, if they are both universities, large firms, or public agencies and so forth), and estimates the potential of actors with organizational proximity to develop strong ties. It is a dummy variable that takes the value one if two actors are of the same organizational kind and zero if they are not, without taking into consideration the kind of organizations they are involved.

In the second version of the model, in order distinguish between organizational kinds another set of dummies is deployed. For every kind of organization a categorical variable is deployed, that separates actors in mutually exclusive categories. So, the cases of actors of the same institutional kind that are considered are: when both actors are universities, research centers, large firms, SMEs, or public agencies with reference to the case that they belong to other kinds of organizations.

The third model is divided in two sub-versions, aiming in both cases to examine the potential of organizational combinations without organizational distance to create strong collaborative ties. The objective is to investigate the preferences in repeated collaborations of the large firms and SMEs (private actors). Consequently, the first version takes the case of large firms groups with universities, research centers and public agencies respectively, with reference the collaborations of the large firms with other kinds of organizations. In the second version of this model, that aims to investigate the preferences of SMEs to repeat collaborations, the equivalent dummy is deployed.

The last set of controls used is the one that checks the cases of relational proximity. For this set of variables in this fourth version, the measurements of degree centrality of all the actors are used, produced by the three types of networks. The degree centrality indicates the position of every actor inside the network, showing how central or peripheral it is in terms of connections. So, the control variables are formed by the absolute difference of degree centrality of the actors. Consequently, the highest the difference is, the more socially distant are two actors.

6.2 The model

In order to draw useful conclusions about the strength of the ties, the collaboration network has been depicted 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 strength of the tie between this two actors or in other words how many times the actors i and j have cooperated between them. The transformation of all the network variables in matrices like this, leads to the generalized formula that estimates the strength of undirected ties:

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

where y_{ij} is the value estimated for the relationship between i and j that this model explains. The matrix x_{ij} includes the explanatory variables that relate i and j. It also includes dummy variables for linkages between local or non-local actors, actors of the same or different institutional kind, and actors with high or low difference in degree centrality.

In more details, the first version of model includes the variables for the geographical, institutional, and organizational proximities. These three kinds of proximity are proved to have significant influence to the knowledge network by previous studies (Balland, 2012). Geographical proximity is represented by the cases when both actors are located inside the region of Trentino (local connections). Institutional proximity relates to the cases when one actor is located inside Trentino and the other in another region of Italy (national connections), or alternatively, in the north part of Italy. Consequently, these two actors belong to the same institutional context, as they act under the same laws, norms, and culture. The reference for both is the case in which one actor is located inside Trentino and the other in another country (global pipelines or international linkages). These cases indicate lack of either geographical or institutional proximities. These two variables are grouped as a local actor could have local, national, or international linkages. Finally, organizational proximity is represented by the case when two actors belong to the same organizational context.

$$Collaboration = Coordination + Funding + Geographical\ Proximity + Institutional\ Proximity + Organizational\ Proximity$$

Analyzing further the notion of organizational proximity in the second version of the model, the present research aims to investigate which kinds of organization prefer to repeat collaborations with organizations of the same kind. Thus, a new dummy is employed that diversifies the cases of two organizations to collaborate by their organizational kind. The categories follow the partition of nodes used in Chapter 4: universities, research centers, large firms, SMEs, and public agencies. The reference is on other kinds of organizations that are not included in these categories.

$$Collaboration = Coordination + Funding + Universities + Research\ Centers + Large\ Firms + SMEs + Public\ Agencies$$

There are cases where organizations seek to repeat collaborations with each other while they are organizationally distant. Such a case is the 'triple helix' that describes the collaboration among state, academia, and industry (Leydesdorff & Etzkowitz, 1998; Etzkowitz & Leydesdorff, 2000). This version of the model aims to analyze the potential of the relationships that private organizations are forming with other institutions to the creation of strong ties. First are analyzed the cases stemming from the collaborations formed by large firms and then those by SMEs with other kinds of organizations. The cases examined for the large firms are when the former are collaborating with universities, research centers and public agencies. The equivalent cases are examined for SMEs as well. The reference for both is the case that they collaborate with other kind of organizations apart from the aforementioned.

$$Collaboration = Coordination + Funding + LFUniversities + LFResearchCenters + LFPublicAgencies$$

and

$$Collaboration = Coordination + Funding + SMEUniversities + SMEResearchCenters + SMEPublicAgencies$$

Finally, the fourth version of the model introduces the notion of relational proximity. This kind of proximity is expressed by the centrality of an actor in the network and how proximate or distant is to the centrality of another actor. The centrality used in this study is the degree centrality (the simplest kind of centrality) of an actor that is the number of connection that an actor has. It is measured for all the three kinds of relationships under investigation (collaboration, coordination, and funding), in terms of absolute differences. This means that when the difference is small, then the two actors are relationally close (both central or both peripheral). When the difference is bigger, then the two actors are relationally distant.

$$Collaboration = Coordination + Funding + DCCollaboration + DCCoordination + DCFunding$$

As this model, in all its versions, is linear, it could be estimated with the standard OLS regression. However, the problem of structural autocorrelation can appear in the rows or the columns of the matrix (Krackhardt, 1987). In order to avoid this problem and evaluate the significance of the coefficients, the Quadratic Assignment Procedure (QAP) can be used. According to Hubert (1987), the QAP-tests are used to make more correct inferences about the significance of this type of coefficients. The advantage of this procedure is that it makes no assumptions about the distribution of the parameters. QAP constructs a permutation distribution that could have been delivered from random datasets with the same structure but different node assignments as the initial dataset. The permutation distribution is constructed by permuting the rows and columns of the dependent variable matrix. So, what actually the p-value represents is the frequency that the coefficients of the permuted dataset are as high as 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.

6.3 Analysis of the Results

The data used in this thesis is relational data used for testing the effect of the several measures of proximity on the strong collaboration ties between the actors. This is the dependent variable of the model and it is of valued (count) type. The data set describes two relations (coordination and funding), also of valued (count) type. The controls for proximity or distance are dummy variables (binary type), where the value one represents the case that the condition posed by the researcher holds or zero when it does not hold. The variable of relational proximity is measured in absolute differences, so it is also of valued type. As with any descriptive statistics, the scale of measurement (binary or valued) does matter in making proper choices about the interpretation and application of the statistical tools. The data that are analyzed in the case of networks are observations about the relations among actors. So, for each matrix the number of observations is $number\ of\ rows\ \times number\ of\ columns$, while for symmetric matrices half of these observations are redundant so there would be $\frac{N \times N}{2}$ observations (where N is the number of actors).

Table 8 below presents the summary of some characteristics of the distribution of the relationships developed between the actors.

Table 8: Univariate statistics of the network variables examined over the entire period (2000-2014)

	Type	Min	Max	Mean	Standard Deviation	Variance
Collaboration 2000-2014	Valued	0	56	0.018	0.162	0.026
Coordination 2000-2014	Valued	0	52	0.002	0.058	0.003
Funding 2000-2014	Valued	0	108	0.001	0.086	0.007
GEOPROX	Binary	0	1	0.004	0.065	0.004
INSTPROX	Binary	0	1	0.028	0.164	0.027
INSTPROX-NORTH	Binary	0	1	0.023	0.149	0.022
ORGPROX	Binary	0	1	0.200	0.400	0.160
BOTHUNI	Binary	0	1	0.040	0.196	0.039
BOTHRES	Binary	0	1	0.052	0.222	0.049
BOTHLF	Binary	0	1	0.038	0.190	0.036
BOTHSME	Binary	0	1	0.063	0.242	0.059
BOTHPUB	Binary	0	1	0.005	0.072	0.005
LFUNI	Binary	0	1	0.078	0.268	0.072
LFRES	Binary	0	1	0.089	0.285	0.081
LFPUB	Binary	0	1	0.043	0.202	0.041
SMEUNI	Binary	0	1	0.103	0.304	0.092
SMERES	Binary	0	1	0.114	0.318	0.101
SMEPUB	Binary	0	1	0.068	0.252	0.063
DCCOLL	Valued	0	945	40.874	60.008	3600.900
DCCOOR	Valued	0	201	4.335	13.121	172.171
DCFUND	Valued	0	2142	2.513	62.111	3857.793

Table 9 presents the correlations between the three network variables (collaboration, coordination, and funding). These are the values of Pearson's correlation performed by the permutation method of QAP. Pearson's correlation is the standard measure when both sociomatrices have valued relations (Hanneman & Riddle, 2005). The medium high correlation between the collaboration and coordination strong ties, suggests a quite strong relationship between the two variables. Changes in one variable bring changes to the other. This is not surprising because of the network structure in projects. As the coordinator is also participant in the project, there is augmented possibility that two actors that have repeated collaborative relationship to have also repeated coordinative relationship. The correlation between the repeatedly collaborating and the funding actors is significantly smaller. This suggests that the funding entity and the repeated funding can be independent from the collaborative network, not affecting the repeated collaboration between the actors. However, at the same time, the funding entity is not isolated from the knowledge transfer as it requires knowledge in exchange. The correlation of the repeated coordination to the repeated funding and vice versa is higher, which might indicate also that coordination actors manage not only knowledge, but also funds that the funding entities give for research on ICT.

Table 9: QAP Correlation of collaboration, coordination, and funding strong ties (2000-2014)

	Collaboration	Coordination	Funding
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)

The statistical analysis was performed with UCInet (Borgatti et al, 2002)

In the Tables 10 – 13, the four different versions of the model (1 – 4) are presented. For each one, a different set of variables is added in order to control for the different kinds of proximity. In all four versions the explanatory variables are the coordination and funding strong ties. In the first version (Table 10) the control dummies are: the case when two actors are geographically proximate (GEOPROX), both the actors to be located in Trentino, the case in which two actors are institutionally proximate (INSTPROX), one actor to be located in Trentino and the other to be located in another region in Italy, and the case in which two actors are organizationally proximate (ORGPROX), the two actors operate under the same organizational context. Alternatively, there is added for comparison a dummy variable for institutional proximity that includes only the cases in which one actor is located in Trentino and the other actor is located in one of the rest of the regions of North Italy (INSTPROX-NORTH). This variable is added to investigate whether the actors located in Trentino perceive as more institutionally proximate the actors located in the north of Italy. In the second version (Table 11), the control variables are testing the institutional proximity of the actors in details. These are the cases where two actors are both large firms (BOTHLF), SMEs (BOTHSME), public agencies (BOTHPUB), research centers (BOTHRES), or universities (BOTHUNI). In the third version (Tables 12a and 12b), the cases where there is lack of institutional proximity are controlled for large firms and SMEs. In these cases, one actor is a large firm and the other one a university (LFUNI), research center (LFRES), or public agency (LFPUB). Respectively for SMEs, the cases are: one actor is an SME, while the other actor is a university (SMEUNI), research center (SMERES), or public agency (SMEPUB). These cases are checked in order to control what kind of institutions the actors choose in order to repeat collaborations, according to the international literature of knowledge transfer from university to industry, research centers to industry, and from public agencies to private large firms or SMEs respectively (Leydesdorff & Etzkowitz, 1998; Etzkowitz & Leydesdorff, 2000). Finally, in the fourth version (Table 13), the relational proximity of the actors is controlled. The control variable set consists of absolute distance in the degree centrality of the two actors under examination, in the collaboration (DCCOLL), coordination (DCCOOR), and funding (DCFUND) networks. This model can draw some valuable conclusions about the choices of the actors to cooperate with other actors according to how much central the latter are in the network.

With respect to the explanatory value of the following regressions (Tables 10-13), there is a slight but insignificant increase in the R^2 when controlling for relational proximity (less than 0.01). In general, the variance explained by the models presented seems to be rather small, but this is acceptable and justified by the structure of the data in networks. Network variables, when examined by the mainstream econometric procedures, appear to have high autocorrelation because of their structure. They use the same nodes connected by different linkages. The problem of this structural autocorrelation is treated by the MP-QAP, producing a rather small R^2. Getting deeper, the results in all the four versions of the model (Tables 10-13), present the effect of the repeated coordination and funding to the repeated collaboration. The effect of the coordination strong ties is positive, significant and high, as in a project, when two actors are linked by a coordination relation, they are also connected by a collaboration relation. So, when two actors have a strong coordinating tie, they are having a strong collaboration tie, as well. In terms of repeated funding, there is a rather small, negative, significant effect, which means that the repeated funding does not affect too much the strong collaboration ties. The funding entities are not directly involved to the knowledge transfer process, however they are still part of it, supporting it and asking for knowledge in return, in the form of product or report.

Table 10: Control for the effect of geographical, institutional, and organizational proximities to the repeated collaboration ties (Model Version 1, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**As Large**	**As Small**	**Standard Errors**
Coordination	1,32933***	0,47615	0,00100	0,00100	1,00000	0,00259
Funding	-0,00596***	-0,00318	0,00100	1,00000	0,00100	0,00201
Geographical Proximity (GEOPROX)	0,03334***	0,01346	0,00100	0,00100	1,00000	0,00504
Institutional Proximity (INSTPROX)	0,00032	0,00033	0,41359	0,41359	0,58741	0,00265
Organizational Proximity (ORGPROX)	0,00911***	0,02253	0,00100	0,00100	1,00000	0,00041
R^2 (Adj)	0.22714	(0.22714)				
Observations (actors)	5,728,842	(2,394)				
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

Table 10a, presented below, constitutes an alternative version of the Table 10 above. In this case, in terms of institutional proximity, institutional proximate actors are considered only those actors located in other regions of north Italy, as these regions have more similar cultural characteristics with Trentino. From this classification is excepted the province of Alto Adige, which although it is border region of Trentino and belong together to the wider region of Trentino - Alto Adige (or Trentino – Sud Tyrol), they do not share the same regional administrative government, and they have considerable institutional differences in terms of culture.

Table 10a: Control for the effect of geographical, institutional, and organizational proximities to the repeated collaboration ties (Model Version 1, 2000-2014) - considering only north Italian regions as institutionally proximate

Dependent Variable: Collaboration Network Strong Ties (2000-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**As Large**	**As Small**	**Standard Errors**
Coordination	1,32933***	0,47615	0,00100	0,00100	1,00000	0,00259
Funding	-0,00596***	-0,00318	0,00100	1,00000	0,00100	0,00255
Geographical Proximity (GEOPROX)	0,03365***	0,01358	0,00100	0,00100	1,00000	0,00428
Institutional Proximity (INSTPROX-NORTH)	-0,00014	0,00013	0,50050	0,50050	0,50050	0,00242
Organizational Proximity (ORGPROX)	0,00911***	0,02253	0,00100	0,00100	1,00000	0,00042
R^2 (Adj)	0.22714	(0.22714)				
Observations (actors)	5,728,842	(2,394)				
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

The first version of the model (Table 10), investigates the effect of geographical, institutional, and organizational proximities on the strong collaborative ties. The econometric analysis shows that proximity matters in the formation of repeated collaborations in the knowledge network, but not in all of its forms. The hypothesis H1 is partially confirmed, as only the geographical and organizational proximities have a significant positive effect on the creation of strong collaboration ties. The institutional proximity does not affect significantly the dependent variable. Hence, actors prefer to cooperate and trust other actors that are located in the same region and operate under the same organizational context. As, these actors do not prefer to collaborate repeatedly with actors that operate under the same institutional context (actors that are located in the same country), we can deduce that they prefer to create global pipelines, collaborating with actors located outside the national borders. So, except from the knowledge that they can obtain from trusted sources located inside the same region, they prefer to import knowledge from distant markets or regions. Making a comparison of the effects of different kinds of proximity on the creation of strong ties, the hypothesis H1a is confirmed. Geographical proximity appears to have stronger effect than any other kind of proximity on the increase of trust and repeated interactions in the knowledge network. Actors prefer to repeat collaboration with co-locating actors, as they prefer to trust organizations with which they can have ‘face-to-face’ contact.

To explain the selection of the national level, as control for institutional proximity between the actors, a comparison between the Tables 10 and 10a, reveals that the institutional proximity even when only the north Italian actors are included remain insignificant, and moreover, it becomes negative. This result means that the actors in the region of Trentino consider that the actors located in the rest of the regions of Italy are acting under the same institutional context, without separating in north and south. This happens because the institutional setting of Trentino differs considerably from the rest of Italian regions in terms of autonomy, however, it is common in national level in terms of culture, constitution, and social norms, revealing that the division between north and south Italy is a more complex issue than it is often suggested.

Table 11: Controlling analytically the effect of institutionally proximate actors to the strong collaboration ties (Model Version 2, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**As Large**	**As Small**	**Standard Errors**
Coordination	1,32891***	0,47600	0,00100	0,00100	1,00000	0,00246
Funding	-0,00566***	-0,00302	0,00100	1,00000	0,00100	0,00264
Both Universities (BOTHUNI)	0,04639***	0,05633	0,00100	0,00100	1,00000	0,00211
Both Research Centers (BOTHRES)	0,00583***	0,00799	0,00400	0,00400	0,99700	0,00199
Both Large Firms (BOTHLF)	-0,00093	-0,00110	0,34166	0,65934	0,34166	0,00209
Both SMEs (BOTHSME)	-0,00500***	-0,00751	0,00200	0,99900	0,00200	0,00181
Both Public Agencies (BOTHPUB)	0,00265	0,00118	0,19381	0,19381	0,80719	0,00367
R^2 (Adj)	0.22975	(0.22975)				
Observations (actors)	5,728,842	(2,394)				
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

Table 11 presents the in-depth analysis of the effect of organizational proximity on the creation of strong ties, when different kinds of organizations are involved. Both universities and research centers have a positive significant effect on the repeated collaborations when they are collaborating with the same kind of organizations. This confirms the hypothesis H2a, that knowledge intensive organizations feel safer by creating strong ties between themselves. Knowledge intensive collaborations constitute a low-uncertainty and low-cost source of expertise and knowledge inside the region. Another interesting result is the negative significant coefficient in the cases of collaboration between SMEs. SMEs avoid repeated collaborations between them. The same happens although in non-significant rate with repeated collaborations between large firms. The private organizations avoid repeating collaborations between them as they compete in terms of knowledge the same time they collaborate. So, they turn to organizations with different kinds of organizational proximity as more secure sources of knowledge.

Table 12a: Controlling the effect of cases where organizational proximity is absent on strong collaborative ties. The cases of combinations of Large Firms and other kinds of organizations (Model Version 3a, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**As Large**	**As Small**	**Standard Errors**
Coordination	1,32934***	0,47615	0,00100	0,00100	1,00000	0,00230
Funding	-0,00555***	-0,00297	0,00100	1,00000	0,00100	0,00201
Large Firms and Universities (LFUNI)	0,04097***	0,06781	0,00100	1,00000	0,00100	0,00211
Large Firms and Research Centers (LFRES)	0,00159	0,00281	0,20979	0,20979	0,79121	0,00188
Large Firms and Public Agencies (LFPUB)	-0,03795***	-0,04749	0,00100	1,00000	0,00100	0,00312
R^2 (Adj)	0.22923	(0.22923)				
Observations (actors)	5,728,842	(2,394)				
*****Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1**						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

Table 12b: Controlling the effect of cases where organizational proximity is absent on strong collaborative ties. The cases of combinations of SMEs and other kinds of organizations (Model Version 3b, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**As Large**	**As Small**	**Standard Errors**
Coordination	1,32938***	0,47616	0,00100	0,00100	1,00000	0,00272
Funding	-0,00557***	-0,00298	0,00100	1,00000	0,00100	0,00259
SMEs and Universities (SMEUNI)	0,04002***	0,07521	0,00100	1,00000	0,00100	0,00208
SMEs and Research Centers (SMERES)	0,00077	0,00153	0,28172	0,28172	0,71928	0,00189
SMEs and Public Agencies (SMEPUB)	-0,04257***	-0,06630	0,00100	1,00000	0,00100	0,00292
R^2 (Adj)	0.22921	(0.22921)				
Observations (actors)	5,728,842	(2,394)				
*****Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1**						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

The third version of the model presents the effect of combinations of organizations on the creation of strong collaborative ties, when the organizational proximity is absent (Tables 12a and 12b). Table 12a presents the cases of large firms with universities, research centers, or public agencies. Tables 12b presents the cases of SMEs with universities, research centers, or public agencies respectively. For both large firms and SMEs the effect on the strong collaborative ties is positive and significant when they are combined with universities. There is no significant effect when they are combined with research centers, while there is a negative significant effect when in the case they collaborate with a public agency. This proves that private organizations consider knowledge intensive organizations as pools of knowledge so they prefer the later for repeated collaborations, especially the universities, instead of other kinds of organizations, confirming the hypothesis H2b. Additionally, in the case of collaboration of a private actors with a public agency, the cost in terms of knowledge to repeat this collaboration, is high. This is because the role of public agencies in the region is mainly supportive within the knowledge transfer process.

Table 13: Controlling the effect of relational proximity on the collaboration strong ties (Model Version 4, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**As Large**	**As Small**	**Standard Errors**
Coordination	1.32366***	0,47411	0,00100	0,00100	1,00000	0,00259
Funding	-0.00508***	-0,00271	0,00100	1,00000	0,00100	0,00067
Collaboration Degree Centrality (DCCOLL)	0.00017***	0,06453	0,00100	0,00100	1,00000	0,00001
Coordination Degree Centrality (DCCOOR)	0.00006	0,00465	0,13786	0,13786	0,86314	0,00006
Funding Degree Centrality (DCFUND)	0.00000	-0,00178	0,29371	0,70729	0,29371	0,00001
R^2 (Adj)	0.23097	(0.23097)				
Observations (actors)	5,728,842	(2,394)				
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

The fourth version of the model controls for the effect of relational proximity on the repeated collaboration (Table 13). It shows that their position in the network, how central or peripheral an actor is, matters for repeating a collaboration. The centrality of the actors is measured in terms of the number of connections (degree centrality). The relationships between actors are measured in terms of absolute differences. The absolute differences demonstrate the reciprocal interest of relationally distant actors to repeat collaborations between them. So, the bigger this measure is, the bigger also the relational distance between the actors (one is more central and the other more peripheral). Among the three controls added (centrality in collaboration, coordination, and funding networks), the important one is the central position of an actor in collaboration network for repeated collaborations. Confirming the hypothesis H3, peripheral actors seek to repeat collaboration with more central and trustful actors in order to strengthen their position in the knowledge network. However, the effect although significant, appears rather small, which means that in the same time also the central actors are seeking to repeat collaborations with other central actors.

6.4 Conclusions

Taking into consideration the results of the study on data of Trentino ICT sector, when two actors are associated with a repeated coordinating relationship, they are also repeatedly collaborating in the same projects. This is because a coordinator participates actively in the knowledge transfer inside a project. Also, when two actors exchange knowledge by repeating collaboration, there is also a possibility that one of the two is chosen repeatedly as coordinator. These coordinators of projects are managing both funds and knowledge. They are trusted by the funding entities to supervise the funds and knowledge allocation to other actors inside the knowledge network. The funding entities are not directly involved to the knowledge transfer process, however, they are still part of it, supporting it and asking for knowledge in return.

Proximity between actors inside the knowledge network of an emerging RIS, in general, is important for the development of trust between actors. However, not in all its forms (Boschma & Frenken, 2010; Balland, 2012). Geographical proximity appears to matter more than other kinds of proximity, as actors prefer to trust organizations with which they can have 'face-to-face' contact. Additionally, actors prefer to import international knowledge to the region instead of extra-regional one, creating global pipelines (Bathelt et al, 2004). The shared institutional characteristics, like laws, language, social norms etc., do not appear to be enough to create the necessary trust for repeated collaboration. Instead, there is a preference for international partners, as the actors of a region prefer to import and exchange knowledge from and with distant RIS and markets. In a fast changing knowledge intensive sector like ICT, it is important to import and integrate knowledge from distant sources. As this procedure of creating 'pipelines' is not spontaneous, and the local actors invest in this kind of knowledge transfer, they seek to develop trust with the distant actors for further cooperation.

Moreover, the organizational proximity of the actors plays an important role in the procedure of repeating a previous collaboration and the creation of a strong collaborative network. In general, for repeated interactions actors seem to prefer other actors from the same organizational background. In this way it is easier for the actors to coordinate their actions, as in case of organizational proximity the two entities act under the same formal or informal organizational context (Boschma, 2005; Balland, 2012; Basile et al, 2012). More specifically, the knowledge intensive organizations (universities and research centers) feel safer in trusting each other. This happens due to the common organizational context they are acting in, that creates more trust to them as participants of projects. Most of the research centers and universities constitute anchor actors of the RIS they belong to, so they act as pools of know-how to be transferred across RIS and markets (Agrawal & Cockburn, 2003). On the other hand, private organizations (large firms and SMEs) avoid repeated collaborations between them, as they are profit oriented, so they collaborate and compete at the same time. This indicates that other private organizations do not constitute safe collaborators. Another hint, especially for the SMEs, is that they cannot afford to invest in R&D activities, while the academic and research institutions can provide them through projects with the necessary knowledge (Assimakopoulos et al, 2016).

Consequently, private organizations turn to organizationally different actors, seeking for knowledge, considering them more secure sources. For them, knowledge intensive organizations, especially universities, constitute pools of high-certainty and low-cost knowledge. This result is in line with the literature on the relations developed between industry and academia, as private sector integrates the knowledge produced in academia and materializes it into products (D'Este et al, 2012; D'Este & Iammarino, 2010; Laursen et al, 2011). On the other hand, they avoid repeated collaborations with public agencies. This is due to the fact that public agencies, especially the regional ones, participate inside the RIS as facilitators of knowledge flows between actors, so actually they try to include different actors in projects every time.

Finally, relational proximity is important for the repeated cooperation of actors. As it is a complex notion, however, and due to preferential attachment reasons (Barabasi & Albert, 1999), it is clear that smaller and more peripheral actors in the knowledge network of an emerging RIS trust more the key central actors, in order to be benefited from the latter's connections, expertise, and know-how, for absorbing knowledge and strengthen their position in the network. Simultaneously, key actors of the RIS tend to cooperate repeatedly with other central actors that can guarantee the efficient knowledge transfer.

The present chapter has three main shortcomings that constitute open discussions for further research. The first one is the fact that the entire knowledge network of the ICT innovation system for fifteen years is considered cumulatively. The fact that in these fifteen years certain economic events appeared, changing probably the behavior of the actors of the knowledge network in terms of collaborations, may produce mixed results. The main external to the RIS global economic event was the economic crisis, due to which, different policies by the province and behavior from the actors are expected. This concern, however, is discussed extensively in the next chapter of this thesis (Chapter 7), which introduces the temporal dimension to the analysis of the knowledge network of an emerging RIS. The second limitation that requires further research, is the analysis of the organizational distance of actors in knowledge network and how it promotes trusted cooperation simultaneously with organizational proximity (Boschma & Frenken, 2010). Finally, there is space for further research in the field of relational proximity, as actors can be relationally proximate in different terms. In this study the degree centrality of the actors is used, but two actors can be central in terms of betweenness (connecting different parts of the network as brokers), closeness (reaching the most remote parts of the network), or eigenvector centralities (being connected with other central actors).

Finally, in order to form its innovation policies, a region should take into consideration the preferences for repeated collaborations of the actors in projects that sketch the dynamics of the RIS knowledge network. The goal of an RIS with high potential, especially in a knowledge intensive field like ICT, is both to strengthen and expand its knowledge network, in order to create and diffuse knowledge efficiently, and consequently to foster the innovation process inside the region. Hence, the region should be aware of the characteristics of actors and the relationships formed between them, the mechanisms under which these relationships are developed, and draw the corresponding strategies. This calls for attention to the proximity parameters of knowledge network actors. The importance of proximity is undoubted, as it creates trust between actors, and consequently repeated strategic partnerships, leading to efficient knowledge transfer inside the region. So, the regions should take into account the proper mixtures of different kinds of proximity as parameters for policy formation.

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CHAPTER 7

DYNAMIC ANALYSIS OF THE RIS KNOWLEDGE NETWORK

As mentioned in the detailed review of the literature (Chapter 2), only in the last decade networks were applied in the fields of economic geography and regional economics. According to Ter Wal and Boschma (2009), only recently, social network analysis techniques were introduced in order to describe how the structure of interactions in regions looks like. Thus, SNA constitutes a promising tool for the investigation of the interactions between the actors of an RIS in a quantitative way.

The majority of the existing empirical studies on networks adopt a static point of view, representing a network of an RIS at a certain point in time (Giulinani & Bell, 2005; Morrison, 2008). The same, however more extended in spatial dynamics, perspective was followed in the previous chapter (Chapter 6), depicting the Trentino ICT innovation system as it was formed in the end of 2014, fifteen years after its birth. On the other hand, in the broader field of network theory, the interest shifted to the network dynamics, incorporating concepts like preferential attachment (Barabasi & Alber, 1999). Preferential attachment is a procedure of network expansion in which the probability of a new node entering the network to create a tie with a certain other node is proportional to the number of ties that this second node already has. So, according to the preferential attachment, the central actors of a network with its expansion remain central, and respectively the peripheral ones remain peripheral.

However, in the field of economic and inter-organizational networks there is still a gap in the application of dynamic network analysis (Gluckler, 2007; Ter Wal & Boschma, 2009). There are few recent attempts in introducing the geographical component, and even fewer that have studied economic or knowledge networks from a time perspective (Cantner & Graf, 2006; Broekel & Boschma, 2012; Balland et al, 2013; ter Wal, 2013; Giuliani, 2013). There are still several questions to be answered, about the mechanisms under which the knowledge network evolves in time. How does an actor decide either to create a new collaboration or to repeat a previous one, either expanding or strengthening the network? Which factors in the environment of the actor play a role in this decision? And consequently, how external negative events affect the evolution of the knowledge network?

This research aims to answer some of the above questions and contributes in filling these gaps in the literature, by introducing the time perspective in the knowledge network of an emerging ICT innovation system, the one of Trentino in Italy. Its main objective is to investigate the evolutions of the ties of the regional knowledge network before and after an external negative event, like the economic crisis of 2007. Thus, for answering the above questions and filling the gap in the literature, a main hypothesis derives:

H4: In a period of high uncertainty (2008-2014) the effect of past co-operations on the occurrence of strong ties between actors is expected to be higher than in a period of low uncertainty (2000-2007)

Assuming that during periods of uncertainty and high risk, the actors in a knowledge network turn to the creation of strong ties with other actors that they trust, the role that plays an actor inside the knowledge network during previous periods creates this trust. Inside the knowledge network, different actors can play different roles considering the multiple relationships that indicate knowledge transfer; so the hypothesis H4 is controlled for each role separately (collaboration, coordination, and funding – see Chapters 4 and 5), and it is argued which role has a more important influence on the evolution of the network in an uncertain period.

A key question in the literature on RIS is how to explain the reasons why actors in an innovation network choose other actors in order to create or strengthen relationships. This happens because of similarities in the attributes of actors which is called homophily or, in the innovation literature, proximity (Boschma, 2005; Boschma & Frenken, 2010; Caragliu & Nijkamp, 2016). As discussed extensively in Chapter 2, the scholars argue on the definition and the dimensions of proximity, however they all agree that proximity is needed in some (although not necessarily all) of its dimensions for connecting the actors of an RIS and enabling the knowledge flows and innovation (Balland, 2012). In this chapter, I control and discuss about the three main dimensions of proximity: geographical, institutional, and organizational proximities (for the definitions see Chapter 2). Hence, the corresponding question is whether the attributes of actors, like proximity, play a role in the evolution of the knowledge network of a region after a negative external event, and form the following hypothesis:

H5: In a period of high uncertainty (2008-2014) the effect of proximity on the occurrence of strong ties between actors is expected to be higher than in a period of low uncertainty (2000-2007)

The different kinds of proximity can be assigned to different attributes of the actors inside the knowledge network. Every actor has a set of characteristics that may affect the way it is deciding to collaborate with another actor. Hence, in this chapter, the effect of the different aforementioned kinds of proximity to the knowledge network is controlled on the evolution of the regional knowledge network before and after crisis. Also, comparisons are performed between the effects on trust creation by previous cooperation and by proximity, and between these effects in certain and uncertain periods.

Summing up, this chapter presents the data and methods employed for the analysis (section 7.1) and describes the evolution of the knowledge network of Trentino ICT innovation system the last fifteen years (section 7.2). In this way, a clear image of the evolution of this specific knowledge network is given. Follows the presentation of the model, that is explaining the mechanisms of the evolution of the regional knowledge network (section 7.3), and the presentation of the detailed results of the analysis with the presence of an external negative event that bring uncertainty to the actors of the network (section 7.4). In the end, the conclusions, the limitations, and the policy implications are discussed (section 7.5).

7.1 Data and Methods

In order to test the above sets of hypotheses, the dataset of the previous chapters (Chapters 4, 5, and 6) on Trentino ICT innovation system was employed. The dataset of this knowledge network on ICT collaborative projects and its study through time can give a description of emerging ICT regional innovation systems, as Trentino constitutes a high potential RIS, and consequently an ideal terrain of study on a high-technological RIS from its birth.

For all the three networks, as described in Chapters 4 and 5, the data was obtained by the lists of collaborative projects of actors located in Trentino. Also in this chapter, the initial data is structured in projects, so every project includes the participants, the coordinator, the funding institutions, the attributes of every entity, and the beginning and termination date of every project (Table 2). Given that there are data on when a project is initiated and terminated, it is possible to "watch" the participation of different kinds of actors in Trentino ICT knowledge network, as well as, the network descriptive measurements through time. For having a better idea of what is going on every year in the knowledge network of Trentino, the measurements of both the cumulative knowledge and the partnership networks are presented (section 7.2). The latter includes only the participants of projects that are active every year, while the former assumes that knowledge is cumulative, so it remains in the network and its actors after the end of every project.

After the description of the knowledge network evolution, to reply the aforementioned research questions, I divided all the three networks (collaboration, coordination and funding) in two time periods, choosing as “breaking point” the end of the year 2007. This separation results in two time periods of similar length, as the entire period under research starts in 2000 and ends in 2014. So, in the first part are included all the collaborative ICT projects initiated from 2000 until the end of 2007, while in the second half all the collaborative ICT projects initiated from 2008 until the end of 2014. The end of the year 2007 was chosen to be the “breaking point”, as it signifies an important external negative event that affected the behavior of the network actors and the later evolution of the regional knowledge network. In 2007 burst out the economic crisis (external negative event), so this research gives an intuition of how this affected the development of emerging regional knowledge networks.

This procedure results in the analysis of the importance of previous cooperation and proximity aspects to the development of trust in the later network. However, this separation of the network is not enough to tell which way of trust creation in uncertain periods matters more. To overcome this difficulty, I divided again the two parts of the network (before and after the economic crisis) in the middle. In this way, a comparison between low and high risk periods can be achieved. For the first low uncertainty period, the division point in time is the end of the year 2003. The first part includes projects initiated from 2000 until the end of 2003, while the second part includes projects initiated from 2004 until the end of 2007. So, the behavior and the preferences of the network actors can be observed for the period before the economic crisis. For the second high uncertainty period, the division point in time is the end of the year 2010. The first part of this period includes projects initiated from 2008 until the end of 2010, while the second part includes projects initiated from 2011 until the end of 2014. From this second division, the behavior of the network actors can be observed for the period during the crisis.

The structure of the raw data in projects can be summarized in four one-mode sociomatrices ($COLL_{20002007}$, $COLL_{20082014}$, $COOR_{20002007}$, and $FUND_{20002007}$) for the first step of analysis, and in two groups of four one-mode sociomatrices ($COLL_{20002003}$, $COLL_{20042007}$, $COOR_{20002003}$, and $FUND_{20002002}$ for the period before crisis, and $COLL_{20082010}$, $COLL_{20112014}$, $COOR_{20082010}$, and $FUND_{20082010}$) for the second part of analysis. In the sociomatrices representing repeated collaboration relationships, both columns and rows are representing the actors participating in collaborative projects for the periods indicated by the indices. In the sociomatrices representing repeated coordination ties, the rows again represent the participating actors in projects, while the columns represent the coordinating actors of these projects, for the same time periods as before. In the remaining sociomatrices that show the repeating funding connections, the rows represent the entities which received funds and the columns the funding entities, for the same periods of time as well. The result of the separation procedure is four and eight square matrices respectively (with the same number of rows and columns), portraying actor to actor relationships; in other words indicating the number of ties between an actor x_i and another actor x_j.

7.2 Description of the Network through Time

Before proceeding to the statistical analysis of the model created in the next section from the sociomatrices above and testing the aforementioned hypotheses, it is useful to describe the evolution of Trentino knowledge network through time. This gives a description on how the knowledge network of an emerging regional ICT innovation system develops from its birth. To achieve this I applied SNA to the dataset of ICT projects of the Trentino actors at the end of every year, for a period of fifteen years (from 2000 until 2014). From the dataset described in Chapter 4, and for every year from 2000 until the end of 2014, two categories of networks were extracted. The first category is the one which concerns the knowledge networks, assuming that knowledge is cumulative every year. In this category, the actors that participate in projects and their connections in the network every year are added to those of the previous year. This happens because the knowledge created from the projects does not disappear after the termination of a project. The second category describes the participation of actors in projects. So, every year, the actors that are participating in projects with their connections are added to the network, while the projects that are terminated in the same year are subtracted from the network with their connections. In other words, in this second category, only the active knowledge actors and ties of every year are presented. Additionally, for every category, the measurements of each one of the networks described in Chapter 5 are analyzed: the collaboration, the coordination, and the funding networks; as each one of these connectivity schemes indicates knowledge transfer.

In Figure 25 (Table h1, Appendix), the evolution of the number of actors that are participating in projects every year is presented. The blue line represents the cumulative number of actors that participate in ICT projects every year, while the red line shows the difference of this cumulative number of actors. Thus, the red line represents the number of actors that are added every year in the knowledge network and participate in the knowledge production of Trentino. The green line shows the number of actors that participate every year in active projects, while the purple line represents the difference of these actors in the knowledge network every year. In general, the actors participating in projects in the Trentino ICT knowledge network are increasing steadily during time and up to the end of the year 2014. Although there are points in time in which the number of actors participating in the network augments sharply, there is one significant slowdown of the expansion of the network in the year 2008. The previous year (2007) the global economic crisis burst out, so the effects of it start to appear at the beginning of the year that follows.

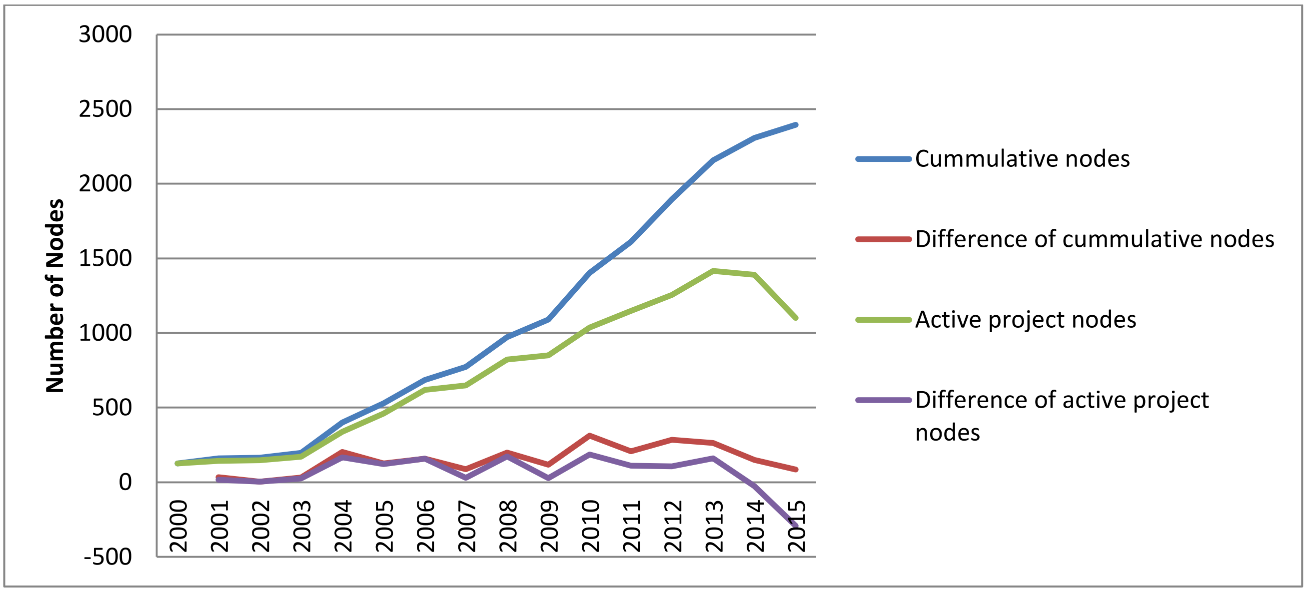

Figure 25: Evolution of Trentino ICT knowledge network number of nodes through time (2000-2014)

The actors participating in the Trentino ICT knowledge network are the same in all the three aspects of connectivity and knowledge transfer described in previous chapters (Chapters 4, 5, and 6). However, the relationships are developed in different ways for each one of these aspects. In the Figure 26 (Table h2, Appendix) the collaboration ties developed every year among the Trentino actors are presented. Again the blue line represents the cumulative collaboration ties and the red line the difference of these ties every year: how many collaboration ties were added to the Trentino ICT knowledge network. The green line represents the collaboration ties of the active projects in every certain year of the network evolution and the purple line presents the differences of these ties every year. Again in 2008, there is a decrease in collaboration activity due to the economic crisis. There is a decrease in both active partnerships from projects and the cumulative collaboration ties, signifying a big shock to the collaboration network in Trentino ICT innovation system. The difference of ties created by the active projects, in 2008, starts declining until it becomes negative, meaning that a lot of projects were terminated, while less projects started. In general, the entire period of these fifteen years, the number of ties on active projects follows the variation of the number of cumulative ties. This gives evidence that the collaboration in previous years tends to repeat while new projects are added. This time dependency of ties is going to be tested in a later section (7.4) of the present chapter.

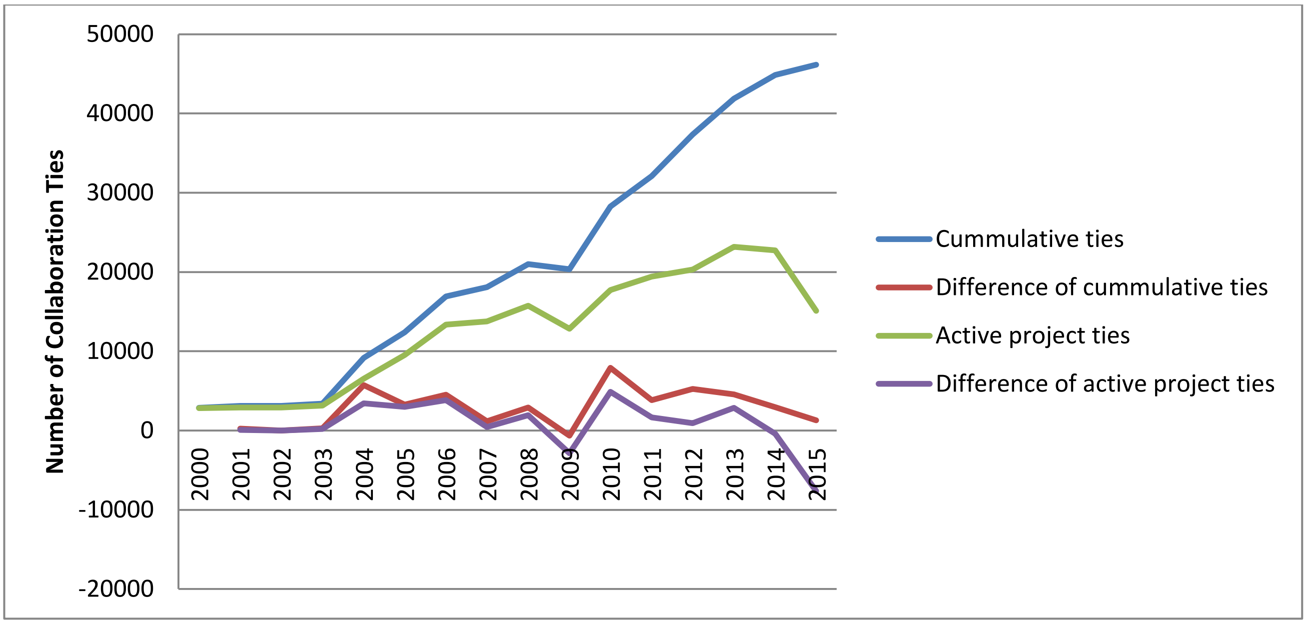

Figure 26: Evolution of the collaboration ties in Trentino ICT knowledge network through time (2000-2014)

The observations on the coordination network in Figure 27 (Table h3, Appendix) are similar with those of the collaboration network. Again in this figure the blue line represents the cumulative number of coordination ties and the red line the differences of these type of ties every year. The green and the purple lines present the number of coordination ties on active projects and their differences every year respectively. In 2008, there is also a decline in coordination ties, however the number of the added active partnerships does not become negative, which means that in the added projects coordination is happening inside Trentino. This supports the evidence of an added number of smaller projects in the RIS.

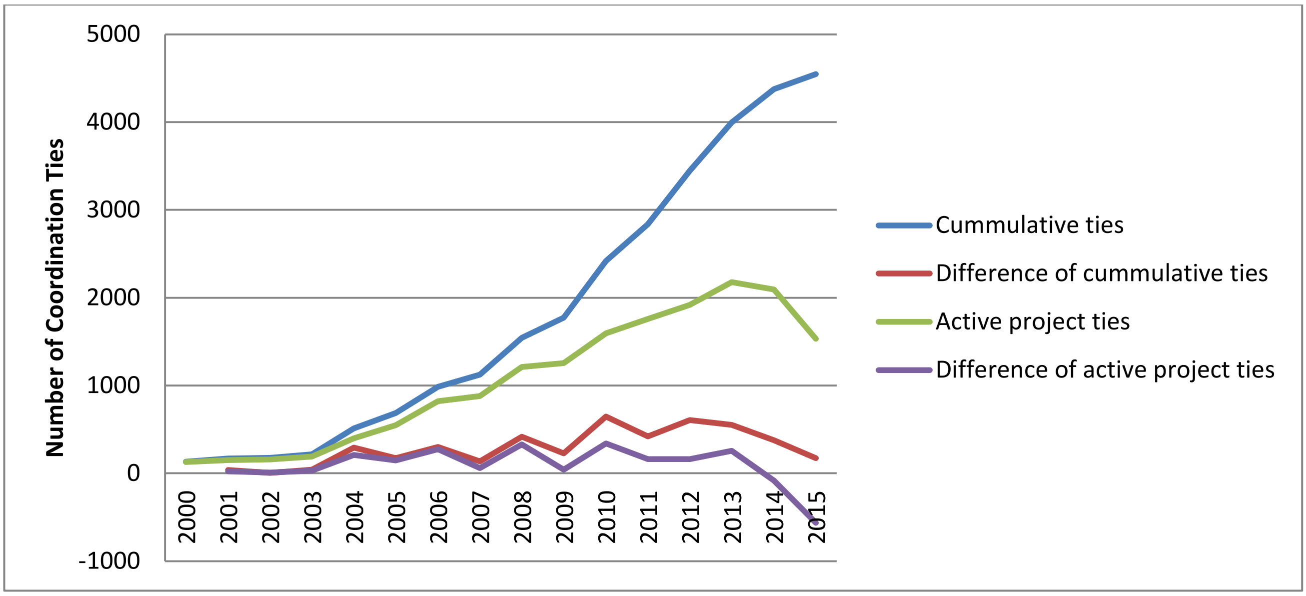

Figure 27: Evolution of the coordination ties in Trentino ICT knowledge network through time (2000-2014)

The Figure 28 (Table h4, Appendix) presents the ties created in the funding network during the time period from 2000 up to the end of 2014. The blue and the red lines represent the cumulative number of funding ties for this period, indicating knowledge transfer through the funding schemes. The green and purple lines indicate the funds in the network circulating by the projects active every year. In terms of cumulative knowledge produced by the project funding a sharp increase in 2007 is observed. This amount declines during 2008, due to the economic crisis. In terms of funds circulating inside the RIS by active projects, again there is a strong inflow in 2007 which declines during 2008, but the incoming funds are not less than the terminated funding schemes.

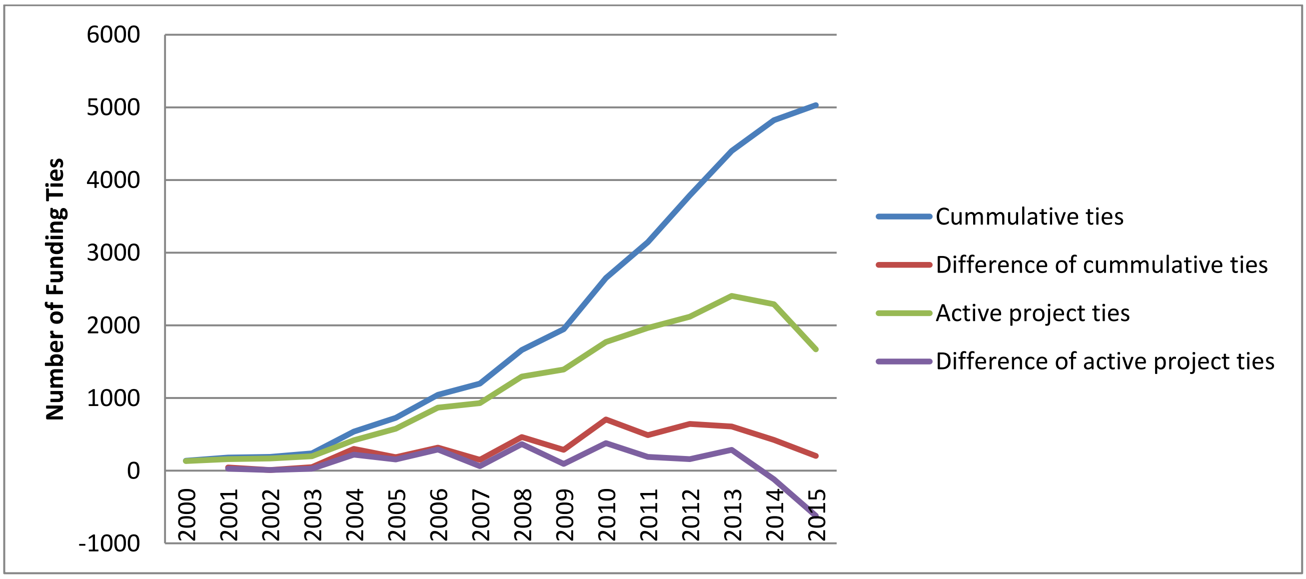

Figure 28: Evolution of the funding ties in Trentino ICT knowledge network through time (2000-2014)

Figure 29a (Table i1, Appendix) is presenting the partition of actors according to their location for every year. They are distinguished in *Local* (actors located inside the region of Trentino), *National* (actors that are located inside Italy but in different regions than Trentino) and *International* (actors located in different countries than Italy). Also in this case, the separation in cumulative and active projects networks is used. In general, the international actors are dominating the RIS of Trentino. There is a stronger inclusion of foreign actors starting from 2003, compared to the national and local ones. During the period from 2000 until 2003, the participation of national and local actors inside the regional knowledge network is negligible. This reveals the collaboration of the few local actors producing knowledge on ICT with exclusively international actors, indicating the introduction of know-how from abroad inside the ecosystem in its early years. In 2003, there is as well a slight inclusion of national and international actors in the knowledge production on ICT innovation. The years in which booms are observed in the number of actors are the years 2007 and 2009, while there is a decrease during 2008. In 2009 it is observed an augmentation in both the numbers of local and national actors included in collaborative projects, enhancing the evidence that during periods of uncertainty proximate actors are preferred for collaboration in projects.

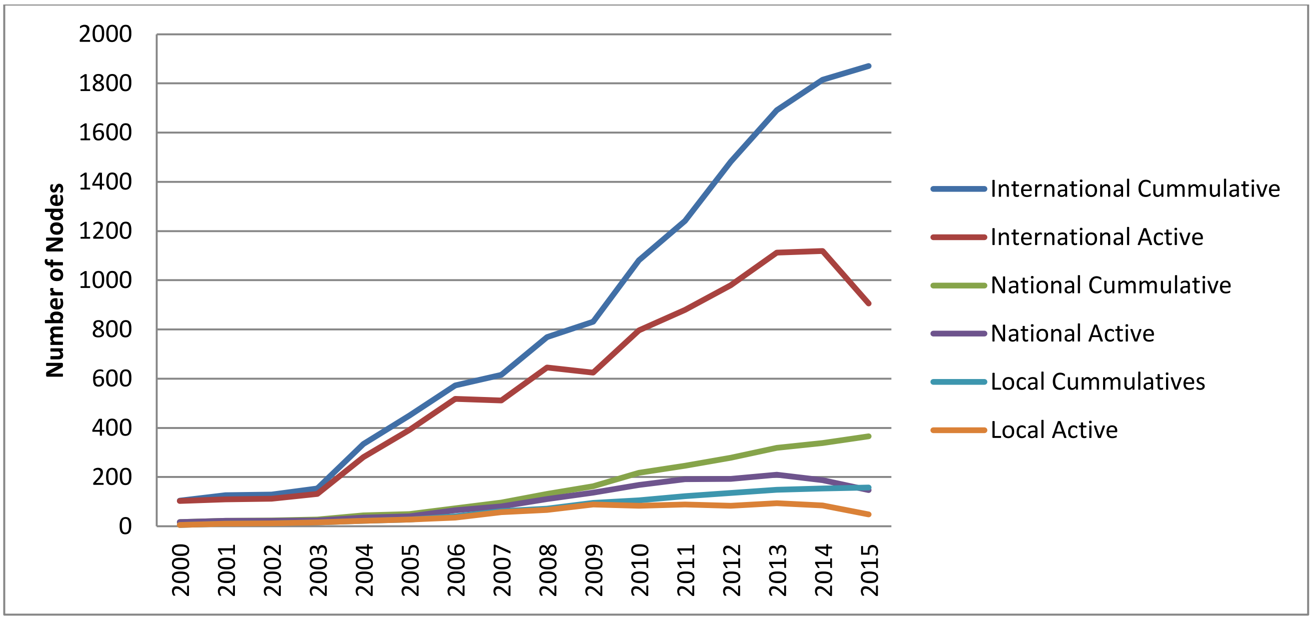

Figure 29a: Partition of actors of Trentino ICT knowledge networks according to their location for the last fifteen years (2000-2014)

Another interesting measurement is the participation of every group of actors in the knowledge network of the RIS in percentages according to their location. Figure 29b (Table i2, Appendix) shows the participation of the actors partitioned according to their location. In this figure, the cumulative and the active project participations follow the same values through time with the partition of the actors in numbers, with minor variations. However, the period between 2007 and 2009 appears to be interesting as the participation of local and national actors in the knowledge network augments, while during the rest of the period it remains stable, with the international actors being dominant.

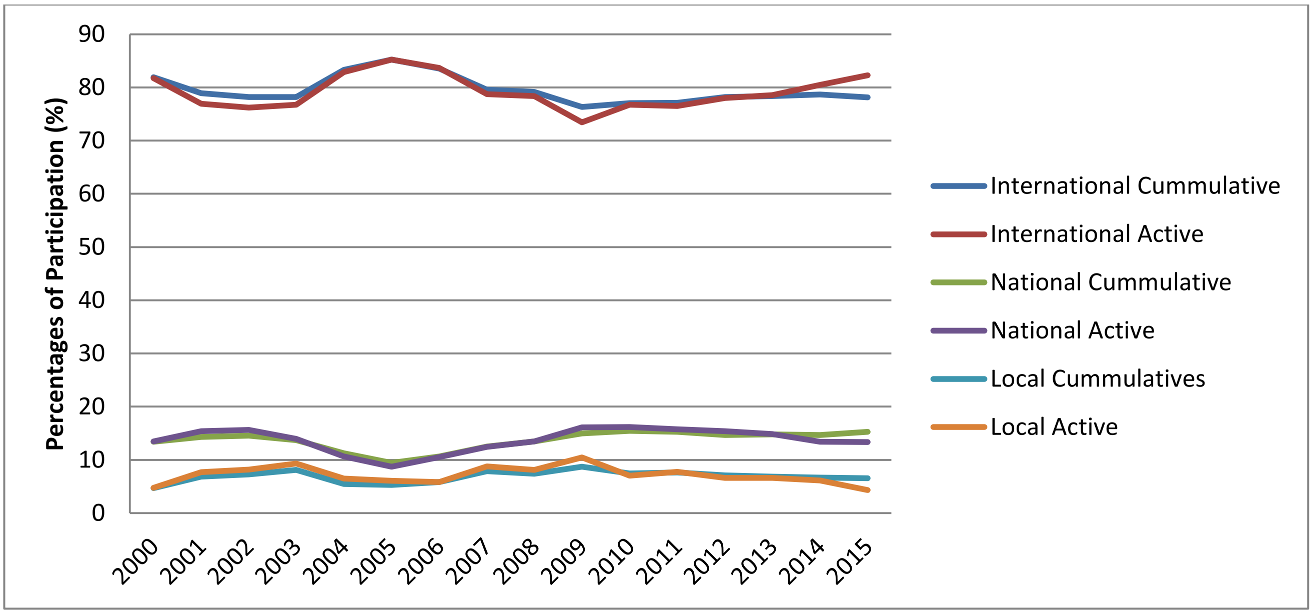

Figure 29b: Participation of actors of Trentino ICT knowledge network according to their location for the last fifteen years (2000-2014) in percentages (%)

Another interesting partition is the one of Figure 30a (Table i3, Appendix) which presents the partition of the actors in numbers according to their organizational kind (universities, research centers, large firms, SMEs, public agencies and other kinds of organizations). Analyzing the measurements of this figure, the high number of collaborating universities since the birth of the Trentino ICT knowledge network is apparent. In the year 2003 there is a significant increase in the numbers of universities, research centers, large firms and SMEs introduced to the knowledge network. In the cumulative measurements in 2010, the number of research centers and SMEs reaches and passes the number of universities inside the network. Then, the number of the large firms follows and reaches the number of universities at the end of 2014, and the public agencies and other kinds of organizations are following with significant lower numbers. The number of public agencies in the network starts to increase in 2007, while the same number for other kinds of organizations increases from 2009. In the measurements of actors participating in active projects, the number of SMEs has a sharp increase in 2009 with a peak in 2013, while it passes in number the participation of all other kinds of organizations.

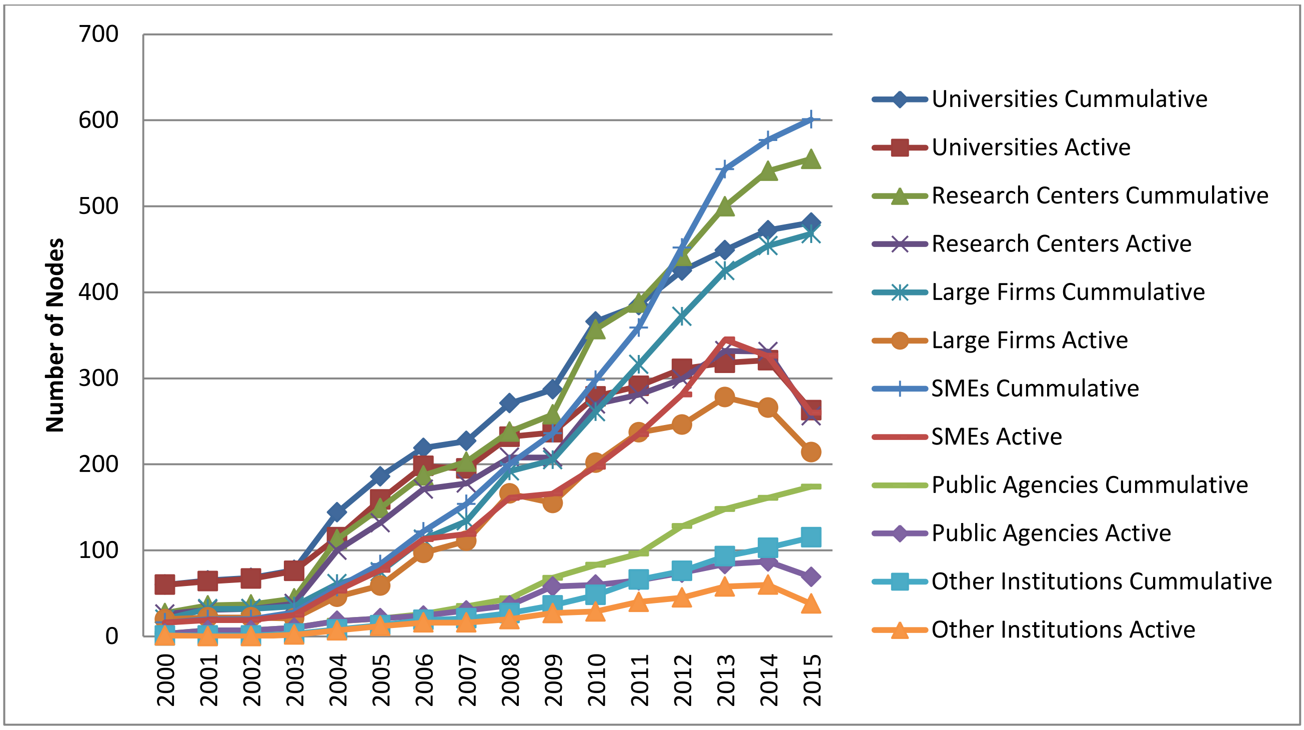

Figure 30a: Partition of actors of Trentino ICT knowledge network according to their organizational kind for the last fifteen years (2000-2014)

Figure 30b (Table i4, Appendix) presents the percentages of participation of every organizational kind inside the Trentino ICT knowledge network through years. It is obvious that in its early years the Trentino knowledge network is dominated by universities whose participation keeps on decreasing through years. During 2004 there is a sharp increase in the participation of the research centers that experiences a slight decrease in the years that follow. The participation of the large firms in the early days of the network is higher than the one of SMEs. The participation of the latter experiences a steady increase during time. There is an image of a regional knowledge network in its birth which depends on knowledge produced by academic institutions and secured by the presence of strong large firms. However, as the RIS is emerging, there is bigger inclusion of SMEs in the knowledge network, until the end of 2014, where the local ICT ecosystem appears to be balanced between public and private actors, with a steady but low participation of public agencies and other kinds of organizations.

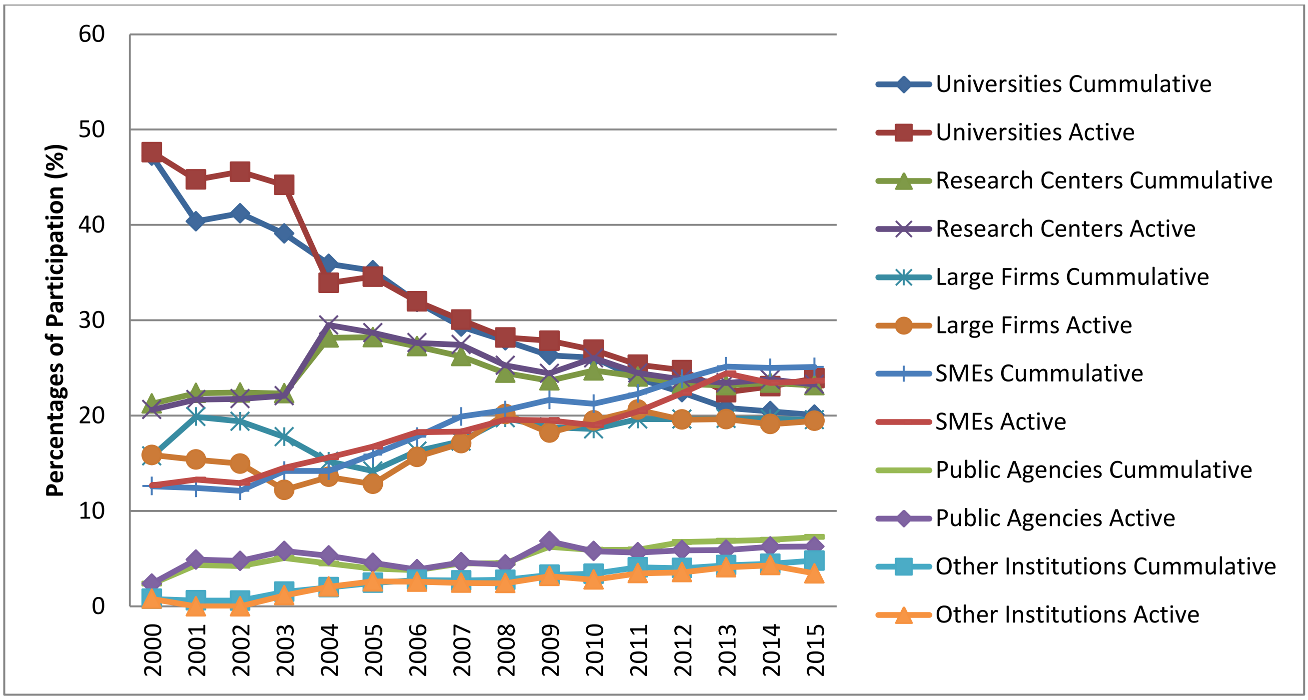

Figure 30b: Participation of actors of Trentino ICT knowledge network according to their organizational kind for the last fifteen years (2000-2014) in percentages (%)

The descriptive analysis of the Trentino ICT knowledge network confirms the intuition that stems from the EUROSTAT data (Figures 6 and 7) presented in Chapter 3, that the region of Trentino was affected as well by the burst of the economic crisis in 2007. Indeed, in the descriptive analysis, a decrease in all measurements, starting from the end of 2007, is observed. Also, in the two periods (before and after the burst of economic crisis) the actors of the regional knowledge network demonstrate different behavioral patterns in terms of collaboration in projects. In order to study these collaborative behaviors, the entire knowledge network of fifteen years is divided in two parts, with 'breaking point' the end of 2007 (Figures 31a,b,c and 32a,b,c, the figures in full page format are available in the Appendix).

Figure 31a, 31b, and 31c: Trentino ICT collaboration, coordination, and funding networks for the period before the burst of economic crisis (2000-2007)

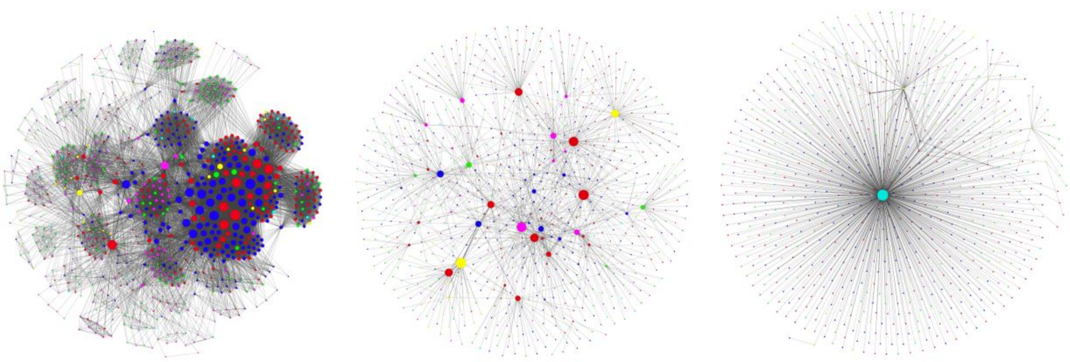

Figure 32a, 32b, and 32c: Trentino ICT collaboration, coordination, and funding for the period that follows the burst of economic crisis (2008-2014)

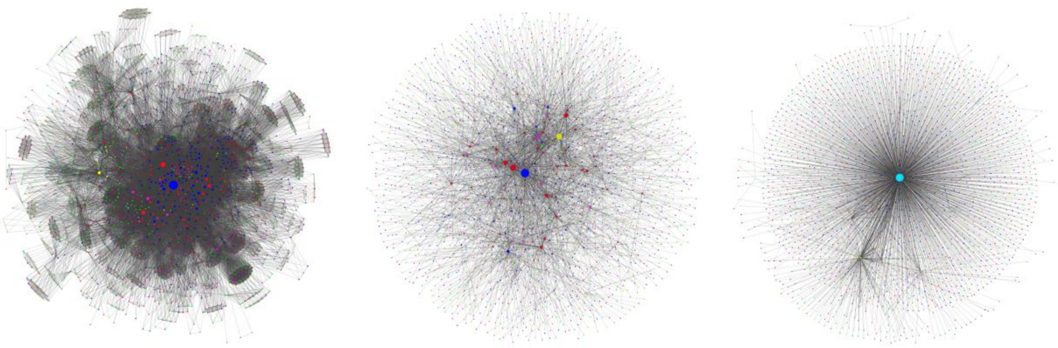

Table 13 corresponds to the networks produced for the two time periods before and after the independent event in the year 2007 (Figures 31a,b,c and 32a,b,c). It presents the overall network descriptive statistics for each one of these networks. Comparing the collaboration networks for the periods from 2000 to 2007 and from 2008 to 2014, the internal structure of the networks in projects offers to them a small world topology (Figures 31a and 32a). Creating two random graphs for each one of the collaboration networks of the two periods with the same number of nodes, the average shortest path lengths for both are similar to the average shortest path length of the original collaboration networks. However, the average clustering coefficient of the random graphs is significantly smaller (0.025) than the one of the original collaboration networks. Comparing these two measurements, small world network properties can be observed in the collaboration network of Trentino for both periods. Small world networks tend to contain cliques, or near cliques, meaning sub-networks and tightly knit communities which have connections between almost any two nodes within them (Watts & Strogatz, 1998). This results to the high clustering coefficient of the network. In the collaboration network of Trentino ICT innovation system this social structure and properties are explained by the underlying structure of the collaborative network in projects that constitute sub-networks and communities. This structure also confirms the presence of high degree nodes in the networks which serve as mediators in the short path length of other nodes in the networks.

According to Watts and Strogatz (1998), knowledge diffuses faster to small worlds networks structure, so in the case of collaboration network of Trentino for both time periods, the SMEs can have fast access in knowledge from all the parts of the network, which in different social architecture for collaboration would not be possible (Pegoretti et al, 2012). The density of the network during the second half, after the independent events, decreases to one third of the initial one. In the same time, the network centralization increases (Table 14). This means that the central actors of the Trentino ICT knowledge network play more significant role in the formation of collaborations during the second time period. This fact also gives a hint of the turn to the local actors to successful collaborators from the past, reducing the opportunities for new collaborative partners to enter in the regional knowledge network, as the Trentino ICT innovation system enters a period of uncertainty after the economic crisis.

Table 14: Descriptive measurement for the collaboration, coordination, and funding networks resulting from the collaborative projects before and after the burst of the economic crisis of Trentino ICT innovation system

	Collaboration Network 2000-2007	Collaboration Network 2008-2014	Coordination Network 2000-2007	Coordination Network 2008-2014	Funding Network 2000-2007	Funding Network 2008-2014
Actors	774	1956	774	1956	780	1970
Ties	18086	33678	1124	3423	1198	3831
Network Density	0.060	0.018	0.004	0.002	0.004	0.002
Average Degree	46.734	34.436	2.904	3.500	3.072	3.889
Network Diameter	4	4	7	7	3	7
Network Degree Centralization	0.202	0.425	0.083	0.090	0.915	0.879
Average Clustering Coefficient	0.905	0.879	0.281	0.250	0.010	0.018
Average Shortest Path Length	2.445	2.560	4.150	3.950	1.162	2.439

The measurements of the descriptive analysis for Trentino ICT innovation system are produced by the software Gephi (Bastian et al, 2009) and UCInet (Borgatti et al, 2002)

In the coordination networks the knowledge is gathered and diffused exclusively by the coordinators of the project and the participating organizations have no exchange of knowledge between them. This assumption serves to observe how the knowledge flows are organized inside the Trentino ICT innovation system (Figures 31b and 32b). Another observation is that the most central actors are the coordinators of the projects which are in the center and the rest of the participants are positioned in their periphery and the periphery of the network. The topology of the coordination network resembles to scale-free. According to Barabasi and Albert (1999) a scale-free network is a random network whose degree distribution follows the power-law asymptotically. The most notable characteristic of a scale-free network, which can be observed to the coordination networks, is the existence of few nodes that have degree considerably greater than the average. These nodes are called hubs and they perform a specific role in the network. In the coordination network they perform the role of the coordinator of projects, distributing and absorbing the knowledge produced by the rest of the participants. The hubs are simultaneously the strength and the weakness of the network. They are the strength because if an error or a malfunction occurs in one of the low degree nodes, the rest of the network is slightly affected. However, they are a weakness as if one of the hubs stops performing, then a big part of the network remains disconnected or a big number of nodes become isolated (Cohen et al, 2000).

The coordination networks for both time periods have considerable lower density and network centralization than the collaboration ones, however during the second time period the average degree slightly increases (Table 14). This means that the already existing hubs of the first period become more important players during the second one.

The last two networks are the funding networks for the two periods before and after the burst of economic crisis. When an entity funds a project also acts as a pool of knowledge that it acquired from previous projects with other actors, and expects to get knowledge in return in the form of reports, patents or products. This representation serves in giving a trace in how the knowledge is generated and transferred according to the funding activity in the Trentino ICT innovation system (Figures 31c and 32c).

In contrast with the other two categories of networks, the funding network for both time periods has low density and high network centralization (Table 14). This is expected as the number of funders is low compared with the number of the entities receiving funds. During the second time period the network diameter and the average short path length are doubled, which means that although the number of funders increased, the access of the funded actors to funds and consequently knowledge became more difficult. The centralization of the funding network during the second period after the external negative event is slightly reduced, as more funding entities are entering the knowledge generation and transfer process.

7.3 The Model

Making a step forward, there is the opportunity to investigate the effects of an external negative event in time on the development of the regional collaborative network, by creating a model. Thus, for answering the aforementioned research questions, it is necessary to decompose them in sub-research questions according to the different aspects of knowledge transfer (collaboration, coordination, and funding) and according to the different kinds of proximity (geographical, institutional, and organizational). Are the strong collaboration, coordination, and funding ties created before an external negative event affecting the evolution of the knowledge network after this event and in which way? Which type of early knowledge transfer has higher effect on the collaboration network during the period of crisis? Are the different proximities (geographical, institutional, and organizational) criteria for developing strong collaborative ties during the economic crisis? Which kind of proximity is more significant after the external negative effect? For giving a meaningful answer to these questions the possible explanatory variables are employed and discussed.

The first set of research questions to be answered is whether the trust created by either previous co-operations or co-operations with proximate actors matter for the inertia of the network during uncertain periods. If yes, then the question arises concerning which of the two kinds of trust creation matters more. Thus, for representing knowledge network at the end of the second half of the period after the burst of the economic crisis for the ICT innovation system of Trentino, it is used the sociomatrix $COLL_{20082014}$ that is produced by the collaboration network of projects in Trentino, from 2008 until 2014. This matrix represents how intensively the actors of Trentino have collaborated in projects the last seven years and constitutes the dependent variable of the first model that is discussed in this chapter.

In order to understand the effect of the different types of knowledge transfer on the later collaborative network, three independent variables are employed. These variables are the three sociomatrices that occur from the first halves (2000-2007) of the collaboration, coordination and funding networks respectively. The collaboration sociomatrix ($COLL_{20002007}$) represents the relationships where transfer of knowledge occurs by the interaction of actors in collaborative projects, assuming that the repeated collaborations between actors during a period of low uncertainty, the most probable is that it creates strong linkages in collaborations during the period uncertainty after this event, helping the network to maintain its inertia. The same is assumed for the coordination and funding repeated relationships of the period before the economic crisis, employing other two variables/sociomatrices ($COOR_{20002007}$ *and* $FUND_{20002007}$).

Additionally, in order to test the model and give answers about the effect of the different kinds of proximity on the trust creation in uncertain periods, a series of controls are added one by one (Table j1, Appendix). The first one is the dummy variable that represents geographical proximity (*GEOPROX*) in the case when the two actors are both located inside the region of Trentino. The second dummy variable is capturing the institutional proximity (*INSTPROX*) as it was discussed in previous chapters (Chapters 2 and 6), and it is the case when one of the actors is located inside Trentino and the second one in another Italian region. The reference variable for the above dummies is the cases where one actor is located inside Trentino and the other in another country. The final dummy inserted controls for organizational proximity (*ORGPROX*), defined in Chapters 2 and 6, and represents the case in which the two actors function in the same organizational context.

However, do the two different ways to create trust have different effects on the evolution of the collaboration network in low and high risk periods? During which of the two periods do they matter more? For answering this kind of questions, the first version of the model is not sufficient. However, useful conclusions can be deduced by splitting the analysis of the data in two, so the effect of the two kinds of trust creation on certain and uncertain periods can be isolated and compared. In the first half (2000-2007), the co-operations created during the low risk period before crisis are considered. For measuring the effect of the trust created from previous co-operations, the collaboration network before the crisis is divided again in two. So, the dependent variable is the collaboration network of the second half of the first period that is from 2004 until the end of 2007 ($COLL_{20042007}$). In order to test the effect of different kinds of co-operations (collaboration, coordination, and funding), three explanatory variables are employed deriving from the collaboration, coordination, and funding networks of the first half of the first period ($COLL_{20002003}$, $COOR_{20002003}$, and $FUND_{20002003}$). Respectively, for measuring the effect of the trust created from previous co-operations on high risk periods, the second half of the knowledge network (2008-2014) is divided in two parts. The dependent variable in this case is the collaboration network of the second half of the uncertain period that is from 2011 until 2014 ($COLL_{20112014}$). In order to test the effect of the different kinds of co-operations (collaboration, coordination, and funding) on the strong ties developed during crisis, three explanatory variables are employed, resulting from the collaboration, coordination and funding networks of the first half of the crisis period ($COLL_{20082010}$, $COOR_{20082010}$, and $FUND_{20082010}$).

Also here, for testing the effect of the proximity in both periods before and after the external negative event, the three control variables of geographical, institutional, and organizational proximities are employed (GEOPROX, INSTPROX, and ORGPROX) and added to the two models one by one (Tables j2 and j3, Appendix).

In order to draw some useful conclusions about the strength of the collaborative ties, the collaboration network of the second period of each model has been depicted as an $n \times n$ adjacency matrix, Y, where for each case, y_{ij} is equal to zero if the actors at i and j positions have no common participation in a project, otherwise y_{ij} is equal to a positive integer that represents the strength of the tie between this two actors or in other words how many times the actors i and j have cooperated between them (Granovetter, 1973). The transformation of all the network variables in matrices like this, leads to the generalized formula that estimates the strength of undirected ties:

$$y_{ij} = a + b'^{x_{ij}} + \varepsilon_{ij} \; for \; all \; i < j,$$

where y_{ij} is the value estimated for the relationship between i and j that this model explains. The matrix x_{ij} includes the explanatory variables and the controls that relate i and j. So, inserting the variables of every model to the general formula, three equations result. The first one explores whether there is an effect from the trust created by co-operations before crisis and by the aspects of proximity to the strength of collaborations created during crisis.

$$COLL_{20082014} = COLL_{20002007} + COOR_{20002007} + FUND_{20002007} + GEOPROX + INSTPROX + ORGPROX$$

The second model measures the effect of previous co-operations and proximity on the trust created by the strength of collaborations during low risk periods (before crisis), while the third one measures the effect of previous co-operations and proximity of the actors on the trust created by the strength of collaborations during high risk periods (during crisis). In this way, by looking at the standardized coefficients, comparisons of the strength of the effects can be made.

$$COLL_{20042007} = COLL_{20002003} + COOR_{20002003} + FUND_{20002003} + GEOPROX + INSTPROX + ORGPROX$$

$$COLL_{20112014} = COLL_{20082010} + COOR_{20082010} + FUND_{200820010} + GEOPROX + INSTPROX + ORGPROX$$

As all the above models are linear models, they could be estimated with the standard OLS regression. However, the problem of structural autocorrelation can appear in the rows or the columns of the matrix (Krackhardt, 1987). In order to avoid this problem and evaluate the significance of the coefficients, the Quadratic Assignment Procedure (QAP) can be used. According to Hubert (1986), the QAP-tests are used to make more correct inferences about the significance of this type of coefficients. The advantage of this procedure is that it makes no assumptions about the distribution of the parameters. QAP constructs a permutation distribution that could have been delivered from random datasets with the same structure but different node assignments as the initial dataset. The permutation distribution is constructed by permuting the rows and columns of the dependent variable matrix. So, what actually the p-value represents is the frequency that the coefficients of the permuted dataset are as high as 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 than five of 100 permutations.

7.4 Interpretative Analysis

The data also to analyze the evolution of the knowledge network in time is relational data used for testing the effect of previous repeated interactions and the several measures of proximity on the strong collaboration ties between the actors during periods of economic slowdown. The dependent variables of the models are of valued (count) type. The data set describes three relations (collaboration, coordination, and funding), also of valued (count) type. The controls for proximity are dummy variables (binary type), where the value one represents the case that the condition posed by the researcher holds or zero when it does not hold. As with any descriptive statistics, the scale of measurement (binary or valued) does matter in making proper choices about the interpretation and application of the statistical tools. The data that are analyzed in the case of networks are observations about the relations among actors. So, for each matrix the number of observations is $number\ of\ rows \times number\ of\ columns$, while for symmetric matrices half of these observations are redundant so there would be $\frac{N \times N}{2}$ observations (where N is the number of actors). Table 15 below presents the summary of some characteristics of the distribution of the relationships developed between the actors for the first model presented in this chapter.

Table 15: Univariate statistics of the variables used in the first model

	Type	Min	Max	Mean	Standard Deviation	Variance
Collaboration 2008-2014	Valued	0	30	0.006	0.086	0.007
Collaboration 2000-2007	Valued	0	18	0.003	0.060	0.004
Coordination 2000-2007	Valued	0	18	<0.001	0.016	<0.001
Funding 2000-2007	Valued	0	21	<0.001	0.024	0.001
GEOPROX	Binary	0	1	0.004	0.065	0.004
INSTPROX	Binary	0	1	0.028	0.164	0.027
ORGPROX	Binary	0	1	0.200	0.400	0.160

Table 16 presents the correlations between the networks under investigation, which are all statistically significant. As mentioned above all the three networks are divided in two time periods, with breaking point the end of the year 2007, which represents an external negative event, like the economic crisis. The strong collaboration ties created before the crisis are correlated positively with the strength of the collaboration ties after the burst of the crisis. The correlation effect is stronger between the coordination network before the external event and the collaboration network after it. A similar but smaller effect there is between the funding network of 2000-2007 and the collaboration network of 2008-2014. The correlations, higher or lower, but always significant, indicate that the evolution of the network after an external negative event is affected by the creation of trust through collaborative ties inside the regional knowledge network before this event. The higher correlation of the later period collaboration relationships with the repeated coordination ties of the previous period can give hints on increased trust in periods of uncertainty to actors that before the external negative event were repeatedly coordinators. The high correlation between the rest of the variables (collaboration, coordination, and funding of the period preceding the independent event) is expected as these variables represent different connections of the same actors during the same time period.

Table 16: QAP Correlation of repeated collaboration, coordination, and funding relationships during low-risk periods and repeated collaboration relationships during high risk periods

	Collaboration 2008 – 2014	Collaboration 2000 – 2007	Coordination 2000 – 2007	Funding 2000 – 2007
Collaboration 2008 – 2014	1.000 (0.000)	-	-	-
Collaboration 2000 – 2007	0.117 (0.001)	1.000 (0.000)	-	-
Coordination 2000 – 2007	0.134 (0.001)	0.288 (0.001)	1.000 (0.000)	-
Funding 2000 – 2007	0.063 (0.001)	0.053 (0.001)	0.188 (0.001)	1.000 (0.000)

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1

Table 17 shows the results of the analysis of the model presented above, adding one by one the controls for proximity. The results are robust as there is no significant change in the coefficients of the variables with every addition. With respect to the explanatory value of the above regressions, there is a slight insignificant increase of R^2 with the addition of every control, but it is no more than 0.001 every time. In general, the variance explained by the model presented seems to be rather small, but this is expected and justified by the structure of the data.

Table 17: Effect of the trust created by previous co-operations and proximity during low uncertainty periods (2000-2007) on the strength of the collaborations during high uncertainty periods (2008-2014)

Dependent Variable: Collaboration Network (2008-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**A Large**	**As Small**	**Standard Errors**
Collaboration 2000-2007	0.11991***	0,08446	0,00100	0,00100	1,00000	0,00119
Coordination 2000-2007	0.53251***	0,10119	0,00100	0,00100	1,00000	0,00343
Funding 2000-2007	0.14205***	0,03960	0,00100	0,00100	1,00000	0,00371
Geographical Proximity	0.03290***	0,02503	0,00100	0,00100	1,00000	0,00202
Institutional Proximity	0.00250**	0,00478	0,02997	0,02997	0,97103	0,00107
Organizational Proximity	0.00422***	0,01978	0,00100	0,00100	1,00000	0,00016
R^2 (Adj)	0.02717	(0.02717)				
Observations (Cases)	5,728,842	(2,394)				
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

Getting deeper into the results of the analysis of the first model, the strong overall knowledge ties formed before an external negative event affect in a positive and statistically significant way the forming of ties in the knowledge network during the period of uncertainty that follows this event. The same is the effect of different types of knowledge transfer (collaboration, coordination, funding) separately to the collaboration network during uncertain periods. This confirms the turn of the actors to more trustful relationships during such periods. The effect of the strong coordination ties of the period before the negative event appears to be stronger than the effect of the other two variables. So the forming of strong (repeated) coordinating ties between two actors in ICT projects during a secure period before a negative external event enhances the strength of the collaboration network after the external shock of the knowledge network. This is important as the actors of the knowledge network turn to actors that were coordinators of project during a previous period, trusting them more than creating new connections, in terms of administration and accumulation of knowledge and funds.

Strong funding ties of low-risk periods also have a significant positive effect on the network structure in insecure periods. Therefore, when an actor funds or gets funded more during a low risk period, it is assumed to be more trustable in terms of knowledge possession during a later period of high risk. Similar, although slightly lower, is the effect of the early strong collaboration ties on the development of the collaborative network of the regional ICT innovation system in periods of crisis. Repeated collaboration during the secure period appears to have smaller effect than the other two types of knowledge transfer on the collaborative network in the period that follows the external negative effects, however, still it indicates augmented trust for the selection of collaborators during an uncertain period.

Concerning the effect of proximity on the tendency of the actors of the knowledge network to create strong ties during periods of crisis, it appears that the trust created also by proximity is important. So, the actors prefer to repeat collaborations during this kind of high-risk periods with trustful actors that are somehow closer to themselves. Proximity between the actors in order to trust and consequently to create strong collaboration ties matters. Analyzing proximity of the different kinds as described in Chapters 2 and 6, their effect on the tendency of the Trentino actors to create strong ties after an external negative event is significant but rather small compared to the trust created by previous co-operations. More important appears to be the case of geographical proximity to the creation of strong collaborative ties during a period of uncertainty, followed by the organizational and the institutional ones. So, during a period of uncertainty, the actors of the regional knowledge network trust first of all other actors located in the same region. Another important case is that they turn to actors in the same organizational context; however the effect is smaller than in the cases where geographical proximity exists. Finally, they can also seek for cooperation with actors located inside Italy, so they act under the same cultural and institutional contexts (sharing common language and habits, as well as common laws and national policies), however the effect of these collaborations does not appear to be as high as the one of the other two types of proximity.

For understanding, though, which of the two effects of trust creation is more important during periods of recession, a comparison of these effects during both certain and uncertain periods is needed. Tables 18 and 19 present the univariate statistics of the variables of the two models controlling for the effect of previous repeated interactions and proximity on later repeated collaborations in the periods before and during economic recession.

Table 18: Univariate statistics of the variables used in the model to describe the behavior of actors before the economic recession

	Type	Min	Max	Mean	Standard Deviation	Variance
Collaboration 2004-2007	Valued	0	14	0.023	0.157	0.025
Collaboration 2000-2003	Valued	0	4	0.005	0.074	0.006
Coordination 2000-2003	Valued	0	4	<0.001	0.020	<0.001
Funding 2000-2003	Valued	0	6	<0.001	0.024	0.001
GEOPROX	Binary	0	1	0.006	0.079	0.006
INSTPROX	Binary	0	1	0.024	0.152	0.023
ORGPROX	Binary	0	1	0.218	0.413	0.171

Table 19: Univariate statistics of the variables used in the model to describe the behavior of actors during the economic recession

	Type	Min	Max	Mean	Standard Deviation	Variance
Collaboration 2011-2014	Valued	0	17	0.005	0.078	0.006
Collaboration 2008-2010	Valued	0	18	0.004	0.063	0.004
Coordination 2008-2010	Valued	0	16	<0.001	0.022	<0.001
Funding 2008-2010	Valued	0	45	<0.001	0.040	0.002
GEOPROX	Binary	0	1	0.005	0.070	0.005
INSTPROX	Binary	0	1	0.030	0.171	0.029
ORGPROX	Binary	0	1	0.201	0.401	0.160

So, I divided in half the two networks (before and after the burst of the economic crisis), for tracing the behavior of the regional network actors in both cases. Table 20 presents the correlations of the repeated interactions that indicate knowledge transfer during the low risk period before the external negative event, while Table 21 presents the correlations of the same repeated co-operations during the high risk period during the economic crisis.

Table 20: QAP Correlation of repeated early collaboration, coordination, and funding relationships and repeated late collaboration relationships during low risk periods

	Collaboration 2004 – 2007	Collaboration 2000 – 2003	Coordination 2000 – 2003	Funding 2000 – 2003
Collaboration 2004 – 2007	1.000 (0.000)	-	-	-
Collaboration 2000 – 2003	0.068 (0.001)	1.000 (0.000)	-	-
Coordination 2000 – 2003	0.041 (0.001)	0.275 (0.001)	1.000 (0.000)	-
Funding 2000 – 2003	0.027 (0.001)	0.025 (0.001)	0.097 (0.001)	1.000 (0.000)

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1

Table 21: QAP Correlation of repeated early collaboration, coordination, and funding relationships and repeated late collaboration relationship during high risk periods

	Collaboration 2011 – 2014	Collaboration 2008 – 2010	Coordination 2008 – 2010	Funding 2008 – 2010
Collaboration 2011 – 2014	1.000 (0.000)	-	-	-
Collaboration 2008 – 2010	0.098 (0.001)	1.000 (0.000)	-	-
Coordination 2008 – 2010	0.085 (0.001)	0.377 (0.001)	1.000 (0.000)	-
Funding 2008 – 2010	0.035 (0.001)	0.088 (0.001)	0.217 (0.001)	1.000 (0.000)

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1

Tables 20 and 21, above, present the correlations between the four network variables (collaboration, coordination, and funding) for the low and high uncertainty periods respectively. These are values of Pearson's correlation performed by the permutation method of QAP. The significance of the correlations of the network variables from 2000 until 2003 and from 2008 until 2010 with the collaboration networks from 2004 until 2007 and from 2011 until 2014 respectively, suggest that there is relationship between these variables. That means that when there is a change in the first set of variables, the evolution of the collaboration network in the second half of both periods under research is affected. However, the amount of the effect for the period after the crisis (Table 17), indicates that the frequency of the previous co-operations affects more the frequency of collaborations in periods of crisis than in low risk periods.

The higher correlation between coordination and collaboration of the same time period is not a surprising fact, because of the network structure in projects. As the coordinator is also participant in the project, there is an augmented possibility that two actors that have repeated collaborative relationship also have repeated coordinative relationship. However, during the period of crisis, the correlation between early funding and coordination appears significantly augmented. This suggest that especially during the first years of crisis, the repeated inflows of funds affect more the management of knowledge in the regional network.

Tables 22 and 23 present the effects of the previous repeated cooperation and proximity on the evolution of the collaboration network during both periods before and after the burst of the economic crisis on 2007. The results are robust as there is no significant change in the coefficients of the variables with every addition (the robustness check is presented analytically in Tables j2 and j3 in the Appendix). With respect to the explanatory value of the regressions, there is a slight insignificant increase of R^2 with the addition of every control, but it is not more than 0.001 every time. In general, the variance explained by the models presented seems to be rather small, but this is expected and justified by the structure of the data.

Table 22: Effect of previous repeated co-operations and proximity on the evolution of the collaboration network in a region during low risk periods (before crisis)

Dependent Variable: Collaboration Network (2004-2007)						
	Coefficients	**Standardized Coefficients**	**P-values**	**A Large**	**As Small**	**Standard Errors**
Collaboration 2000-2003	0.12422***	0.05863	0.00100	0,00100	1,00000	0,00515
Coordination 2000-2003	0.17510***	0.02203	0.00100	0,00100	1,00000	0,01618
Funding 2000-2003	0.14811***	0.02280	0.00100	0,00100	1,00000	0,02082
Geographical Proximity	0.11001***	0.05520	0.00100	0,00100	1,00000	0,00777
Institutional Proximity	-0.01083***	-0.01044	0.00400	0,99700	0.00400	0,00471
Organizational Proximity	0.01956***	0.05133	0.00100	0,00100	1,00000	0,00080
R^2 (Adj)	0.01095	(0.01094)				
Observations	642,402					
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

Table 23 presents the effect of the previous cooperation on the evolution of the collaboration network during periods of certainty. So, the dependent variable is the late collaboration network in the period before crisis (2004-2007). The independent variables employed are the early collaboration, cooperation, and funding network during this period of certainty (2000-2003). Also, the model controls for the effect of the geographical, institutional, and organizational proximities on the late collaboration network.

Both the trust created by previous co-operations and proximity appear important for the evolution of the collaboration network during low risk periods. The trust created from co-operations appears to be more important for the actors than the one created by the aspects of proximity for the evolution of the collaborations in projects in the region. The position of an actor as coordinator and the repeated funding are affecting more than the previous collaborations the trust created for future strong collaborations in the regional network during safe periods. In general, proximity is important for the creation of strong collaborations, but not always in a positive way. During low risk periods, geographical proximity has a significant positive effect on the creation of a strong collaborative network. The same happens with the organizational proximity. Institutional proximity, though, has a significant negative effect on the creation of strong collaborative ties, revealing that local actors avoid repeating collaborations with national actors during periods of economic safety. The actors prefer to collaborate with other actors outside the national borders, importing knowledge from distant regions, and consequently expanding the network.

Table 23: Effect of previous repeated co-operations and proximity on the evolution of the collaboration network in a region during high risk periods (during crisis)

Dependent Variable: Collaboration Network (2011-2014)						
	Coefficients	**Standardized Coefficients**	**P-values**	**A Large**	**As Small**	**Standard Errors**
Collaboration 2008-2010	0.09414***	0.07551	0.00100	0,00100	1,00000	0,00121
Coordination 2008-2010	0.18634***	0.05236	0.00100	0,00100	1,00000	0,00264
Funding 2008-2010	0.03200***	0.01656	0.00200	0,00100	0,99900	0,00249
Geographical Proximity	0.02703***	0.02437	0.00100	0,00100	1,00000	0,00186
Institutional Proximity	0.00142*	0.00310	0.08492	0,99700	0,91608	0,00094
Organizational Proximity	0.00382***	0.01964	0.00100	0,00100	1,00000	0,00016
R^2 (Adj)	0.01359	(0.01359)				
Observations	3,859,260					
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

Table 23 presents the effect of the previous cooperation on the evolution of the collaboration network during periods of crisis. So, the dependent variable is the late collaboration network in the period after the burst of economic crisis (2011-2014). The independent variables employed are the early collaboration, cooperation, and funding network during this period of crisis (2008-2010). Also, the model controls for the effect of the geographical, institutional, and organizational proximities on the late collaboration network.

During periods of uncertainty, both the trust created by previous co-operations and proximity appears important for the evolution of the collaborative network in high risk periods. Like in the previous case, the trust created by previous co-operations appears to be more important for the actors than the one created by their proximity for the evolution of the collaboration network of the region. The position of an actor as coordinator is affecting more than the other two relationships indicating knowledge transfer the trust created for future strong collaborations in the regional network during crisis periods. Also, the repeated transfer of knowledge through collaborations during the first period affects more the strength of the ties during the later period than the repeated funding. Moreover, proximity appears to have a significant effect on the creation of a strong collaborative network during periods of crisis. Again, the geographical proximity demonstrates the highest positive effect among the three different proximity aspects. It is followed by the organizational and institutional proximities whose effect on the strength of the collaboration in the region is weaker.

Looking at the standardized coefficients of the variables in the two tables (Tables 22 and 23), comparisons between the high and low risk periods are possible. During the period of crisis the overall trust deriving from the different aspects of knowledge transfer in the network augments. In a period of crisis (2008-2014), the roles of actors in the knowledge network (collaboration, coordination, and funding) of early periods (2008-2010), affect significantly the later period (2011-2014), because without an increase in the funds (internal or external) and while facing a period of economic slowdown, trust from previous co-operations becomes important. They prefer to repeat previous co-operations than to search for new co-operators with which they had not any transfer of knowledge before. Thus the hypothesis H4 is confirmed.

Getting deeper into the effect of previous co-operations, the effect of the trust created from previous collaborations and coordinations has increased during the period of crisis, while the effect of the repeated funding was reduced, although by a small amount compared to low risk periods. This indicates the effort of the actors to find funding from different sources during the crisis, in order to repeat their trustful collaborations.

Although the overall proximity is important for the creation of trustful strategic relationships in both periods (before and after the external negative event), this overall effect during periods of economic recession is significantly reduced. So, the hypothesis H5 is rejected, as in the periods of crisis proximity actually matters less than in periods of low risk, despite it is associated with lower transaction costs and risk in collaborations. Analyzing the proximity effect on the collaborative network of the two periods, the effects of geographical and organizational proximities decreased during the high risk period, while the effect of institutional proximity reduced in intensity and significance, but remained positive. This is explained by the high investment in cost and effort that actors put in the global pipeline creation, so going through a period when the funding is restricted, bringing to them uncertainty, they seek to repeat collaborations with actors that operate under the same institutional context.

Getting deeper to the three different notions of proximity analyzed in this part of the thesis, the coefficient of the geographical proximity decreases in the period of economic recession. Possible explanation of this result is that even if the crisis affected almost all the European economies, its impact across regions even within the same country was highly diversified.

Economic actors in a specific region could therefore be less willing to cooperate with other actors in the same area because they probably share the same difficulties. Rather Trentino actors could be interested in developing connections with agents outside their regional system but with some other characteristics in common; this speculation seems to be supported by the finding about institutional proximity. In this case, in fact, the sign of the coefficient changes in the crisis period from negative to positive, suggesting that in a phase of recession Trentino actors increased their collaboration with agents outside the region but inside Italy.

Another interesting finding concerns the organizational proximity. Also in this case the coefficient of this kind of proximity reduces in the period of crisis. This means that, other factors constant, actors are less likely than before to collaborate with agents of the same organizational kind. This may reflect the fact that in a period of recession characterized by tight budget constraints of public and private funding bodies, the actors try to diversify their portfolio of collaborations, cooperating also with kinds with agents of various organizational kinds.

7.5 Conclusions

This research constitutes a first attempt to analyze the mechanisms of creation of collaborative relationships in the ICT sector in the knowledge network of an emerging RIS. The repeated co-operations fostering knowledge generation and transfer (Granovetter, 1973) formed in such an RIS during low uncertainty periods help its knowledge network to maintain its inertia and resilience (Ferrary & Granovetter, 2009; Newman & Dale, 2005) after the intervention of an external negative event, like an economic crisis. The actors after an external shock and during periods of uncertainty turn to other actors for collaboration with which they have developed trust from previous co-operations. So, trust from previous interactions has a positive effect on the development of the knowledge network during periods of crisis. Moreover, the position of actors in an RIS as coordinators of projects makes them preferable in terms of trust and consequently collaboration in uncertainty periods, as they are conceived as hubs of accumulated knowledge from previous periods. With respect to funding behavior, during high risk periods, the actors seek money from different sources available, not depending only on the traditional public funding sources.

An alternative form of developed trust discussed in this study, is the trust developed by attributes shared between the actors. In general proximity (Boschma, 2005; Broekel & Boschma, 2012) of all the three forms discussed affects positively the knowledge network, derived from the repeated collaborations between actors with similar characteristics irrespectively of the intervention of the external negative event. However, this effect loses its intensity during periods of economic recession. In other words, although proximity of actors is associated with lower transaction costs and collaboration risk, it matters less in periods of crisis than in periods of economic growth. So, during such periods of slowdown, the actors turn more for collaboration to trustful actors with which they have cooperated in the past, than to actors with which they share common characteristics. This has as result the maintenance of the inertia of the network, while in low risk period, the actors prefer to expand the knowledge network of the region investing in global pipelines and importing knowledge from distant regions.

Summing up, the results of the analysis of the present study show that when facing an external shock like the economic crisis, previous collaborations are extremely important to predict the occurrence of relationships in period of crisis. In particular, this is true for the actors who played the role of coordinators in previous projects. Interestingly enough, the coefficient associated to the funding is lower, suggesting that the capability of managing a project is more important than the access to funds. Also, the decreasing coefficient of funding suggests that actors turn to not traditional funding sources, in order to acquire the necessary funds for maintaining the inertia of the knowledge network. Proximity, in all its aspects (geographical, institutional and organizational), however, counts less than the trust created from previous strategic co-operations.

Overall, this paper showed that in periods of crisis trust matters for the inertia and resilience of the knowledge network of an emerging RIS, while in terms of previous co-operations it matters more in periods of crisis than in other periods. Thus, the importance of the trust to the development of the knowledge network of an RIS during periods of crisis can suggest policy implications. Even if there is no measurement for the outcome of the collaborations under research, we can assume that if actors keep on cooperating with the same partners they find it beneficial in uncertain periods. From a policy perspective, this could be interpreted as the success of the regional program of incentives, also when compared with the general trend of the ICT sector in the recent years. Obviously causal linkages between policy actions, the network strong relationships and their outcome require further research, but the findings of this research suggest that the actions undertaken by the local authorities fostered the inertia of the network in a period of recession and, as a consequence, tighter budget constraints for both firms and public bodies.

CHAPTER 8

CONCLUSIONS AND POLICY IMPLICATIONS

In the last three decades the attention of governments and supra-national institutions is on the systems of innovation in national, sectoral, and regional levels. The characteristics, the potential, and the dynamics of every region differ significantly in terms of innovation, constituting the RIS an important level of analysis for the policy formation on the innovation process (Cooke, 2001).

According to the literature innovation is considered a locally embedded process, while the benefits from localization include the knowledge creation and transfer that contribute to the competitive advantage of the region (Asheim & Gertler, 2004). The significance of the knowledge and knowledge networks in the innovation process of the region is a central element of RIS. So, the literature has produced several conceptual frameworks in order to describe knowledge spillovers and flows inside, from within and towards the knowledge network of the RIS (Cooke, 2001; Fischer, 2001; Bathelt et al, 2004).

A key chapter in this literature on knowledge networks and their flows is how the agents develop trust with other agents in order to create and transfer knowledge. The trust between agents can be developed in two ways: either when the agents trust other agents with which they successfully cooperated in the past (Granovetter, 1983; Krackhardt & Stern, 1998), or when they trust other agents with which they share similar characteristics (Boschma, 2005).

For analyzing empirically the knowledge network, the literature used SNA to describe and analyze relationships between individuals, firms, and institutions that indicate knowledge flows and spillovers. Thus, SNA constitutes a useful tool, contributing further to the analysis of the knowledge network and the RIS in spatial and temporal aspects. While the use of SNE to describe and analyze knowledge flows over space is widely adopted (Giuliani & Bell, 2005; Morrison, 2008), it is less clear how to study the evolution of these connections over time (ter Wall & Boschma, 2009; 2011). There are some attempts in the literature to investigate the dynamics of the knowledge networks (Cantner & Graf, 2006; Broekel & Boschma, 2012; ter Wal, 2013); however, they are still far from being explored. There are gaps in the literature in studying in a more profound way the drivers of the knowledge network evolution.

The aim of this thesis is to contribute to the understanding of the mechanisms under which the knowledge network of an emerging RIS on knowledge intensive technologies evolves. This chapter presents the conclusions of the present study on the evolution of knowledge networks (section 8.1), the scientific contribution of the results and the policy implications deriving from them (section 8.2), and the gaps in the literature remaining to be explored by future research (section 8.3).

8.1 Conclusions of the Research

According to the classification of Cooke (2001), Trentino fulfills the criteria to be considered a high potential RIS. Although ICT field is just a part of the innovative activity in Trentino, given the amount of investment of the regional government in the last fifteen years, it can be considered an important field of the regional innovative activity. So, the analysis of the knowledge flows and spillovers inside the region is crucial for giving a complete idea of how this network functions, and what is needed to be taken into consideration by the regional policy makers.

For understanding how the knowledge flows in the knowledge network of an RIS, it is important the identification of the key actors of the network and the understanding of their role in the knowledge transfer process. Shortly, the knowledge network of Trentino is characterized, in a big part, by collaborations with foreign actors, demonstrating the ability of its actors to import knowledge from distant regions by creating global pipelines. An amount of this knowledge is managed inside the region, with the local actors playing the important role of knowledge brokers and strategic collaborators. The main funding source for the Trentino innovative activity is the European Commission, while a smaller but also significant part of funds is provided by the local government and other smaller sources.

In terms of the knowledge generated exclusively inside Trentino (local buzz), the local actors repeat co-operations between them, benefiting from the collocation, while a big amount of local SMEs participates in the knowledge creation and diffusion. The local knowledge network of Trentino appears to be particularly inclusive, as really few local actors cooperate exclusively with actors outside the region. In terms of funds, a big number of local actors are funded exclusively by external funds, while the rest (mainly the local SMEs) are supported financially by the local government and other considerably smaller funding entities.

However, the heart of Trentino ICT knowledge network is a tightly knit core of three local key actors: the local university, the biggest local research center, and the local government. All of them play different roles inside the knowledge network, enhancing the knowledge creation and transfer in the region. The local university supports the connectivity of the region with distant regions, as it participates in international projects, collaborating with national and international knowledge intensive institutions, constituting a pivotal actor that connects Trentino with the rest of the world. The role of the biggest local research center is similar, although its connections appear more balanced between local actors and actors external to the region. The special role of this actor is that connects the public research with the private organizations. Consequently, it is focused on the application of the knowledge produced in the region. Finally, the local government plays a crucial role as regional knowledge gatekeeper and coordinator, including the less favored local actors, like the local SMEs, into the knowledge transfer and innovation process. It is the main local funding entity, allowing the peripheral actors to have access to funds and knowledge.

Except for the conclusions stemming at the regional level and concern the special characteristics of every RIS, we can also extract conclusions on the evolution of the knowledge network of an emerging RIS, by understanding the mechanisms under which the network is operating spatially and temporally.

The preferences of the actors in terms of shared characteristics (proximity) for creating trustful collaborations constitute an important element of the spatial evolution of the network. Proximity between actors inside the knowledge network of an emerging RIS is, in general, important for the development of trust between actors. However, not in all its forms (Boschma & Frenken, 2010; Balland, 2012). Actors appear to develop trust with other actors that have a certain mix of proximity or distance.

More specifically, actors prefer to trust organizations with which they can have ‘face-to-face’ contact (geographical proximity), benefited by the co-location (local buzz), while they prefer to import international knowledge to the region instead of extra-regional one (institutional proximity), creating global pipelines (Bathelt et al, 2004). In a fast changing knowledge-intensive sector like ICT, it is important to import and integrate knowledge from distant sources. As this procedure of creating 'pipelines' is not spontaneous, and the local actors invest in this kind of knowledge transfer, they seek to develop trust with the distant actors for further cooperation.

In general, the organizational proximity of the actors plays an important role in the creation of a strong collaborative network. So, it is easier for the actors to coordinate their actions, as the two organizationally proximate actors are operating under the same organizational context (Boschma, 2005; Balland, 2012). Especially, the knowledge intensive organizations (universities and research centers) feel safer in trusting each other, creating more trust as participants of collaborative projects. Paradoxically, the private organizations (large firms and SMEs) avoid to repeat collaborations between them for two reasons: on the one hand, the cost of R&D activities and the knowledge acquirement through the private co-operations is high, so they turn to more ‘cheap’ sources of knowledge (Assimakopoulos et al, 2016), and on the other hand, they do not feel safe in repeating co-operations with each other, as their relationships are not only cooperating but also competing with each other. Consequently, they turn to organizationally different actors, seeking for knowledge. For them, knowledge intensive organizations, especially universities, constitute pools of high-certainty and low-cost knowledge (D’Este et al, 2012; D’Este & Iammarino, 2010), while they avoid repeating collaborations with public agencies, as the role of public agencies in the knowledge network is mostly supportive and facilitating, than generating knowledge.

Finally, the relational proximity is important for the repeated cooperation of actors. As it is a complex notion, however, and due to preferential attachment reasons (Barabasi & Albert, 1999), it is clear that smaller and more peripheral actors in the knowledge network of an emerging RIS trust more the key central actors, in order to be benefited from the latter's connections, expertise, and know-how, for absorbing knowledge and strengthen their position in the network. At the same time, key actors of the RIS tend to cooperate repeatedly with other central actors that can guarantee the efficient knowledge transfer.

By the temporal point of view, this research analyzes the mechanisms of creation of collaborative relationships in ICT knowledge network of an emerging RIS. The repeated co-operations fostering knowledge generation and transfer (Granovetter, 1973) formed in such an RIS during low uncertainty periods help its knowledge network to maintain its inertia and resilience (Ferrary & Granovetter, 2009; Newman & Dale, 2005) after the intervention of an external negative event, like the economic crisis. The actors after an external shock and during periods of uncertainty turn to other actors for collaboration with which they have developed trust from previous co-operations. So, trust from previous interactions has a positive effect on the development of the knowledge network during periods of crisis.

An alternative form of developed trust discussed in this study, is the trust developed by attributes shared between the actors. In general proximity (Boschma, 2005; Broekel & Boschma, 2012) of all the three forms discussed affects positively the knowledge network, derived from the repeated collaborations between actors with similar characteristics irrespectively of the intervention of the external negative event. However, this effect loses its intensity during periods of economic recession. In other words, although proximity of actors is associated with lower transaction costs and collaboration risk, it matters less in periods of crisis than in periods of economic growth. So, during such periods of slowdown, the actors turn more for collaboration to trustful actors with which they have cooperated in the past, than to actors with which they share common characteristics. This has as result the maintenance of the inertia of the network, while in low risk periods, the actors prefer to expand the knowledge network of the region investing in global pipelines and importing knowledge from distant regions.

Summing up, we can reach to interesting conclusions out of the present research, concerning both the ICT knowledge network of Trentino, but also the knowledge network of every emerging RIS. Concerning this specific region, its special characteristics are analyzed, while the key actors and knowledge flows inside it are identified. Every pivotal actor performs a different role inside the network, which constitute it necessary for the maintenance of the inertia and resilience of the knowledge network in the region. Concerning the generalized part of the analysis, the present study shows the importance of proximity, so those actors acquire the trust needed for creating a strong knowledge network fostering the innovation process. However, being in line with the existing literature (Boschma & Frenken, 2010), the present thesis claims that the effect of every kind of proximity is not the same for the necessary trust creation, while there are cases where distance in attributes it is preferred.

Inserting the temporal aspect, the results of analysis in the present study show that when facing an external shock like the economic crisis, previous collaborations are extremely important to predict the occurrence of relationships in periods of crisis. In particular, this is true for the actors who played the role of coordinators in previous projects. Interestingly enough, the coefficient associated to the funding is lower, suggesting that the capability of managing a project is more important than the access to funds. Also, the decreasing coefficient of funding suggests that actors turn to not traditional funding sources, in order to acquire the necessary funds for maintaining the inertia of the knowledge network. Proximity, in all its aspects (geographical, institutional and organizational), however, matters less than the trust created from previous strategic co-operations.

The present research has shortcomings deriving from the type and the structure of the data. These shortcomings are two and they are connected with each other. The first and main one is the lack of data on the outcome of the collaborative projects under study. Hence, the contribution in the growth and development of the RIS of the knowledge network developed in Trentino the last fifteen years cannot be measured. So, what the present thesis investigates is the evolution of the regional

ICT knowledge network and its value per se. This problem leads also to the second shortcoming of the present research which is inability to evaluate the collaborative projects and distinguish the importance of their contribution to the regional knowledge network. This might lead to a bias on findings. However, the results of the present research demonstrated that previous relationships in collaborative projects have a positive impact on the present number of repeated collaborations. This effect is estimated for any kind of previous relationship, disregarding if these relationships occurred within regionally, nationally, or internationally funded projects. In other words, this means that the effect of previous strong connections is considered by the present research the same, whatever the type of the program is.

8.2 Scientific Contribution and Policy Implications

The conceptual framework is conceived as a tool for assessment of innovation polices or any kind of policy aimed at creating networks of economic actors. The assessment of policies is usually just based on the measurement of some specific output (patents, reports, papers etc.), while the creation of a network is a valuable externality per se. Economic actors involved in a network could come back to cooperate together in the future; they shared skills; they learnt from each other. The assessment of the value of these connections has to be based on a deep knowledge and theoretical foundation of network interactions. The present work is aimed at contributing in this line of research.

The major contribution of this work is the multidimensional framework that treats the knowledge network of an emerging RIS, in both spatial and temporal dimensions, representing the evolution of the network. Knowledge networks constitute complex entities, consisting of multiple relationships and levels that evolve over time. Until now the majority of the existing literature, assesses the knowledge network in a static way, with few attempts to represents its dynamics. The present research, contributes to the investigation of the knowledge network dynamics, integrating them in a common multidimensional network, while it identifies the behavioral patterns of the actors during high risk periods.

Moreover, from the present thesis, a series of policy implications arises concerning Trentino but also the emerging RIS in general. At the regional level, from the analysis it appears that the local initiative created in a span of fifteen years a solid network of knowledge transfer in the field of

ICT in the region of Trentino. However, there are some points the local policy makers should take attention to. The region should attract more private investments in the field of ICT as it is the public rather than the private sector that drives the development of the knowledge network in the region. Also, there is space for more cooperation between the local actors; the local government should promote the collaboration of less connected local actors with the more central ones in the knowledge network. Although the province should continue supporting the knowledge creation and transfer in Trentino, by allowing the access to knowledge and funds to the least favored local actors, it should strengthen in the same time the role of the local innovation hubs in the knowledge network, constituting them important in the managing of knowledge imported and exported to the region.

Except for the policy implications at the regional level, the present work indicates the importance of the multidimensional analysis for every RIS knowledge network, in order to understand the mechanisms under which a regional knowledge network evolves. Thus, a region in order to form its innovation policies should take into consideration the preferences for repeated collaborations of the actors in projects that sketch the dynamics of the RIS knowledge network. The goal of an RIS with high potential, especially in a knowledge intensive field like ICT, is both to strengthen and expand its knowledge network, in order to create and diffuse knowledge efficiently and consequently to foster the innovation process inside the region. Hence, the region should be aware of the characteristics of actors and the relationships formed between them, the mechanisms under which these relationships are developed, and draw the corresponding strategies. It is significant that it takes into account the proximity parameters of knowledge network actors. The importance of proximity is undoubted, as it creates trust between actors, and consequently repeated strategic partnerships, leading to efficient knowledge transfer inside the region. So, the regions should take into account the proper mixtures of different kinds of proximity as parameters for policy formation.

Overall, this thesis showed that in periods of crisis trust matters for the inertia and resilience of the knowledge network of an emerging RIS, while in terms of previous co-operations it matters more in periods of crisis than in other periods. Thus, the importance of the trust to the development of the knowledge network of an RIS during periods of crisis can suggest policy implications. Even if there is no measurement for the outcome of the collaborations under research, we can assume that if actors keep on cooperating with the same partners they find it beneficial in uncertain periods. From a policy perspective, this could be interpreted as the success of the regional program of incentives, also when compared with the general trend of the ICT sector in the recent years. So, the findings of this research suggest that the actions undertaken by the local authorities fostered the inertia of the network in a period of recession and, as a consequence, tighter budget constraints for both firms and public bodies.

8.3 Opportunities for Future Research

The study of emerging RIS in a knowledge intensive field, like ICT, by the use of the dataset on collaborative projects of Trentino, Italy, has certain shortcomings that constitute open discussions for further research. More in details, the following lines of future research are identified.

Trentino appears similar characteristics with other autonomous regions in Europe (e.g. with the Basque Country in Spain, or the federal states of Germany). However, each of these cases has different degree of autonomy. So, the first line of future research is the comparative analysis with different emerging RIS, characterized by different territorial features and conditions (either under the state of autonomy or not). The knowledge network differs from one RIS to other, although it constitutes a significant element for all the regional systems of innovation. Thus, allocating different data in the same conceptual framework, different structures and patterns in the knowledge creation and diffusion may appear.

Further, in the present research, another limitation that requires further research is the organizational distance of actors in knowledge network and how it promotes trusted cooperation simultaneously with organizational proximity (Boschma & Frenken, 2010). Also, there is space for further research in the field of relational proximity, as actors can be relationally proximate in different terms. In this study the degree centrality of the actors is used, however two actors can be central in terms of betweenness (connecting different parts of the network as brokers), closeness (reaching the most remote parts of the network), or eigenvector centralities (being connected with other central actors).

Overall, this paper showed that in periods of crisis trust matters for the inertia and resilience of the knowledge network of an emerging RIS. However, does it matter more in periods in which internal policies aimed to expand or strengthen the regional network are applied? This is an issue that requires further research and can be analyzed by comparing the mechanisms of creation of new relationships (strong and weak) of RIS under other external conditions.

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APPENDIX

Figure 15a: Entire Trentino ICT collaboration network (2000-2014)

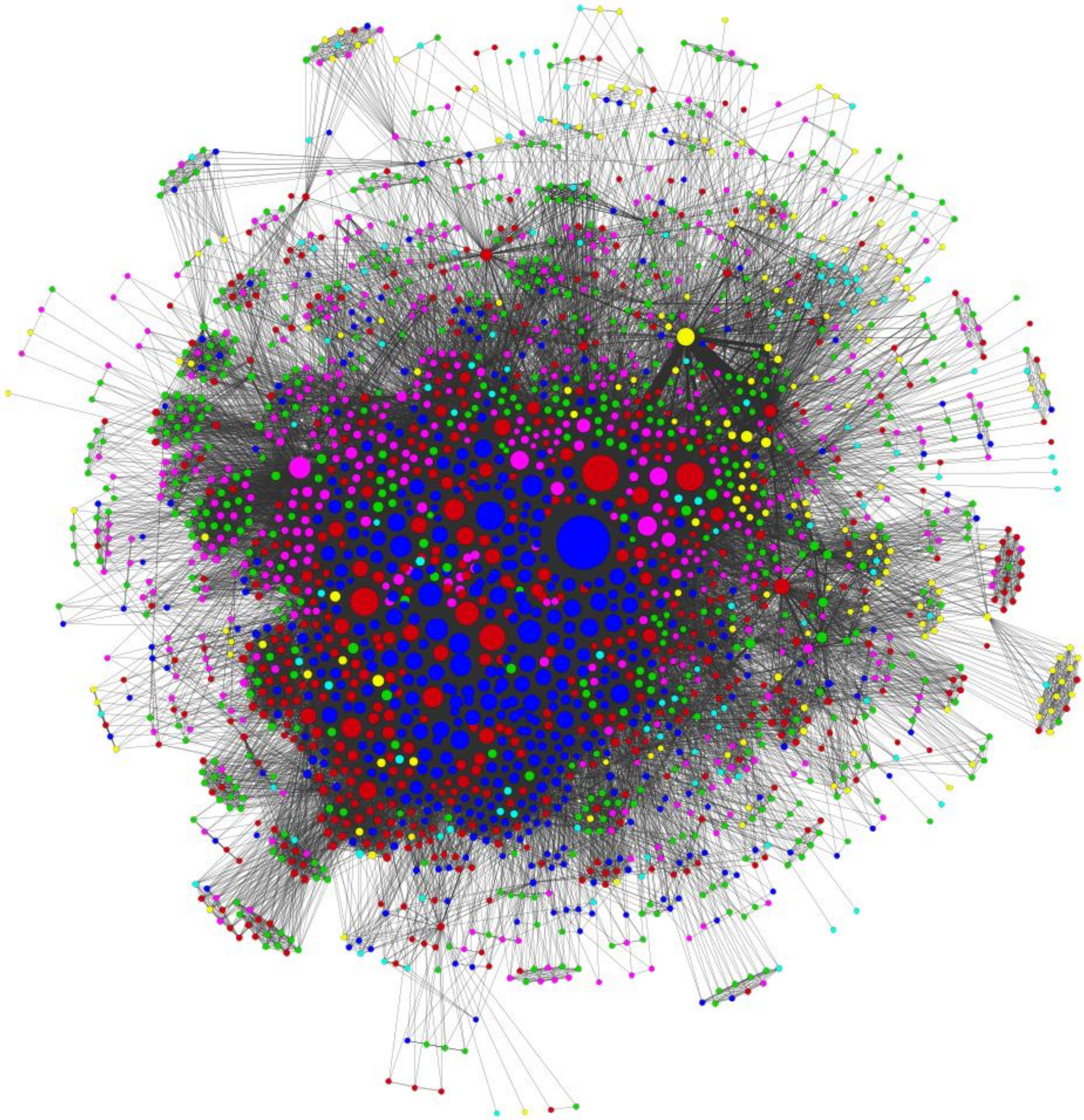

Table a1: Top 10 Degree Centrality Entire Collaboration Network

Actor	Position	Kind	**Degree**	Closeness	Betweenness	Normalized Betweeness	Eigenvector
UNITN	LOC	UNI	**1556**	0,624	825.867	0,289	1,000
FBK	LOC	RES	**956**	0,572	455.466	0,159	0,706
CNRS	INT	RES	**641**	0,523	47.100	0,016	0,492
CREATE-NET	LOC	RES	**637**	0,543	221.139	0,077	0,370
CNR	NAT	RES	**592**	0,539	115.015	0,040	0,386
POLITECHNIC UNI MADRID	INT	UNI	**566**	0,537	82.771	0,029	0,338
CEA	INT	RES	**528**	0,517	36.022	0,013	0,395
PAT	LOC	PUB	**517**	0,525	137.754	0,048	0,551
UNI LUND	INT	UNI	**479**	0,506	18.531	0,006	0,366
ETH ZURICH	INT	UNI	**465**	0,522	37.575	0,013	0,352

Table a2: Top 10 Betweenness Centrality Entire Collaboration Network

Actor	Position	Kind	Degree	Closeness	**Betweenness**	Normalized Betweenness	Eigenvector
UNITN	LOC	UNI	1556	0,624	**825.867**	0,289	1,000
FBK	LOC	RES	956	0,572	**455.466**	0,159	0,706
CREATE-NET	LOC	RES	637	0,543	**221.139**	0,077	0,370
PAT	LOC	PUB	517	0,525	**137.754**	0,048	0,551
ENGINSOFT	LOC	IND	401	0,513	**121.384**	0,042	0,164
CNR	NAT	RES	592	0,539	**115.015**	0,040	0,386
GRAPHITECH	LOC	RES	273	0,503	**103.774**	0,036	0,110
POLITECHNIC UNI MADRID	INT	UNI	566	0,537	**82.771**	0,029	0,338
DISTRETTO TECNOLOGICO TRENTINO	LOC	RES	158	0,483	**64.492**	0,023	0,093
FRAUNHOFER	INT	RES	352	0,509	**59.488**	0,021	0,203

Table a3: Top 10 Closeness Centrality Entire Collaboration Network

Actor	Positio n	Kind	Degree	**Closeness**	Betweenness	Normalized Betweenness	Eigenvector
UNITN	LOC	UNI	1556	**0,624**	825.867	0,289	1,000
FBK	LOC	RES	956	**0,572**	455.466	0,159	0,706
CREATE-NET	LOC	RES	637	**0,543**	221.139	0,077	0,370
CNR	NAT	RES	592	**0,539**	115.015	0,040	0,386
POLITECHNIC UNI MADRID	INT	UNI	566	**0,537**	82.771	0,029	0,338
PAT	LOC	PUB	517	**0,525**	137.754	0,048	0,551
CNRS	INT	RES	641	**0,523**	47.100	0,016	0,492
ETH ZURICH	INT	UNI	465	**0,522**	37.575	0,013	0,352
CEA	INT	RES	528	**0,517**	36.022	0,013	0,395
UNIBO	NAT	UNI	321	**0,516**	30.344	0,011	0,265

Table a4: Top 10 Eigenvector Centrality Entire Collaboration Network

Actor	Position	Kind	Degree	Closeness	Betweenness	Normalized Betweenness	**Eigenvector**
UNITN	LOC	UNI	1556	0,624	825.867	0,289	**1,000**
FBK	LOC	RES	956	0,572	455.466	0,159	**0,706**
PAT	LOC	PUB	517	0,525	137.754	0,048	**0,551**
CNRS	INT	RES	641	0,523	47.100	0,016	**0,492**
INFORMATICA TRENTINA	LOC	RES	316	0,503	49.164	0,017	**0,395**
CEA	INT	RES	528	0,517	36.022	0,013	**0,395**
CNR	NAT	RES	592	0,539	115.015	0,040	**0,386**
CREATE-NET	LOC	RES	637	0,543	221.139	0,077	**0,370**
UNI LUND	INT	UNI	479	0,506	18.531	0,006	**0,366**
KTH ROYAL INSTITUTE OF TECHNOLOGY	INT	UNI	435	0,507	23.986	0,008	**0,357**

Figure 15b: Entire Trentino ICT coordination network (2000 – 2014)

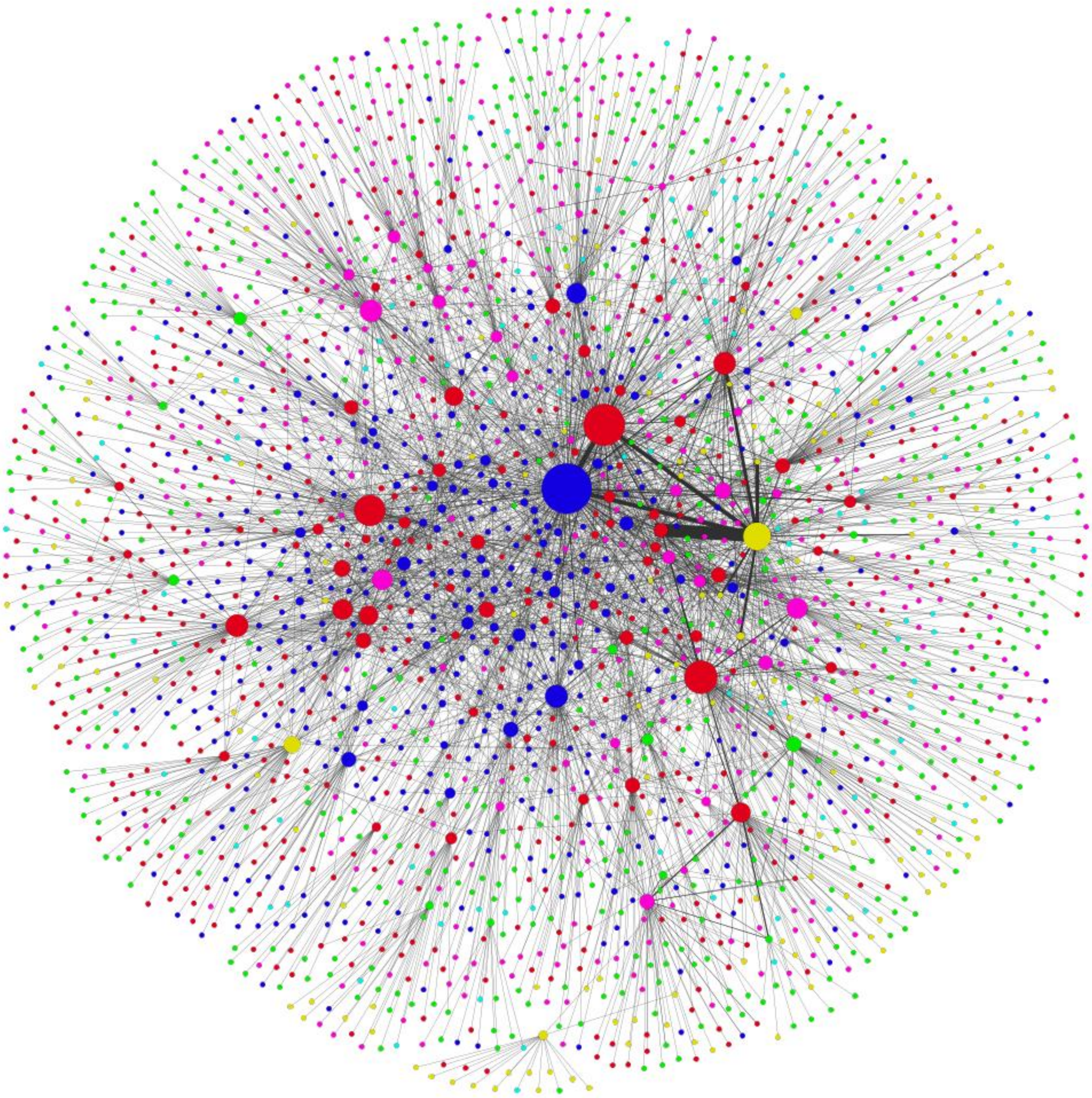

Table b1: Top 10 Degree Centrality Entire Coordination Network

Actor	Position	Kind	**Degree**	Closeness	Betweenness	Normalized Betweenness	Eigenvector
UNITN	LOC	UNI	**306**	0,443	1.064.070	0,372	0,600
PAT	LOC	PUB	**253**	0,372	247.966	0,087	1,000
FBK	LOC	RES	**241**	0,404	523.172	0,183	0,564
CREATE-NET	LOC	RES	**159**	0,377	285.271	0,100	0,175
CNRS	INT	RES	**123**	0,364	174.677	0,061	0,065
TRENTO RISE	LOC	RES	**121**	0,365	122.287	0,043	0,324
INFORMATICA TRENTINA	LOC	RES	**115**	0,357	74.825	0,026	0,796
UNI INNSBRUCK	INT	UNI	**85**	0,360	117.387	0,041	0,059
ENGINSOFT	LOC	IND	**84**	0,348	192.491	0,037	0,056
TELECOM ITALIA	NAT	IND	**84**	0,360	106.213	0,067	0,088

Table b2: Top 10 Betweenness Centrality Entire Coordination Network

Actor	Position	Kind	Degree	Closeness	**Betweenness**	Normalized Betweenness	Eigenvector
UNITN	LOC	UNI	306	0,443	**1.064.070**	0,372	0,600
FBK	LOC	RES	241	0,404	**523.172**	0,183	0,564
CREATE-NET	LOC	RES	159	0,377	**285.271**	0,100	0,175
PAT	LOC	PUB	253	0,372	**247.966**	0,087	1,000
ENGINSOFT	LOC	IND	84	0,348	**192.491**	0,067	0,056
CNRS	INT	RES	123	0,364	**174.677**	0,061	0,065
GRAPHITECH	LOC	RES	83	0,320	**158.757**	0,055	0,085
INRA	INT	RES	80	0,321	**131.402**	0,046	0,020
DISTRETTO TECN TRENTINO	LOC	RES	62	0,349	**129.711**	0,045	0,089
UNI EDINBURGH	INT	UNI	70	0,367	**125.947**	0,044	0,056

Table b3: Top 10 Closeness Centrality Entire Coordination Network

Actor	Position	Kind	Degree	**Closeness**	Betweenness	Normalized Betweenness	Eigenvector
UNITN	LOC	UNI	306	**0,443**	1.064.070	0,372	0,600
FBK	LOC	RES	241	**0,404**	523.172	0,183	0,564
CREATE-NET	LOC	RES	159	**0,377**	285.271	0,100	0,175
PAT	LOC	PUB	253	**0,372**	247.966	0,087	1,000
CNR	NAT	RES	43	**0,368**	108.600	0,038	0,035
UNI EDINBURGH	INT	UNI	70	**0,367**	125.947	0,044	0,056
TRENTO RISE	LOC	RES	121	**0,365**	122.287	0,043	0,324
CNRS	INT	RES	123	**0,364**	174.677	0,061	0,065
UNI INNSBRUCK	INT	UNI	85	**0,360**	117.387	0,041	0,059
TELECOM ITALIA	NAT	IND	84	**0,360**	106.213	0,037	0,088

Table b4: Top 10 Eigenvector Centrality Entire Coordination Network

Actor	Position	Kind	Degree	Closeness	Betweenness	Normalized Betweenness	**Eigenvector**
PAT	LOC	PUB	253	0,372	247.966	0,087	**1,000**
INFORMATICA TRENTINA	LOC	RES	115	0,357	74.825	0,026	**0,796**
UNITN	LOC	UNI	306	0,443	1.064.070	0,372	**0,600**
FBK	LOC	RES	241	0,404	523.172	0,183	**0,564**
TRENTO RISE	LOC	RES	121	0,365	122.287	0,043	**0,324**
CONSORZIO COMUNI TRENTINI	LOC	PUB	17	0,282	0	0,000	**0,201**
TRENTINO NETWORK	LOC	PUB	31	0,336	12.981	0,005	**0,192**
CREATE-NET	LOC	RES	159	0,377	285.271	0,100	**0,175**
APSS	LOC	PUB	15	0,302	23	0,000	**0,149**
DISTRETTO TECN TRENTINO	LOC	RES	62	0,349	129.711	0,045	**0,089**

Figure 15c: Entire Trentino ICT Funding Network (2000-2014)

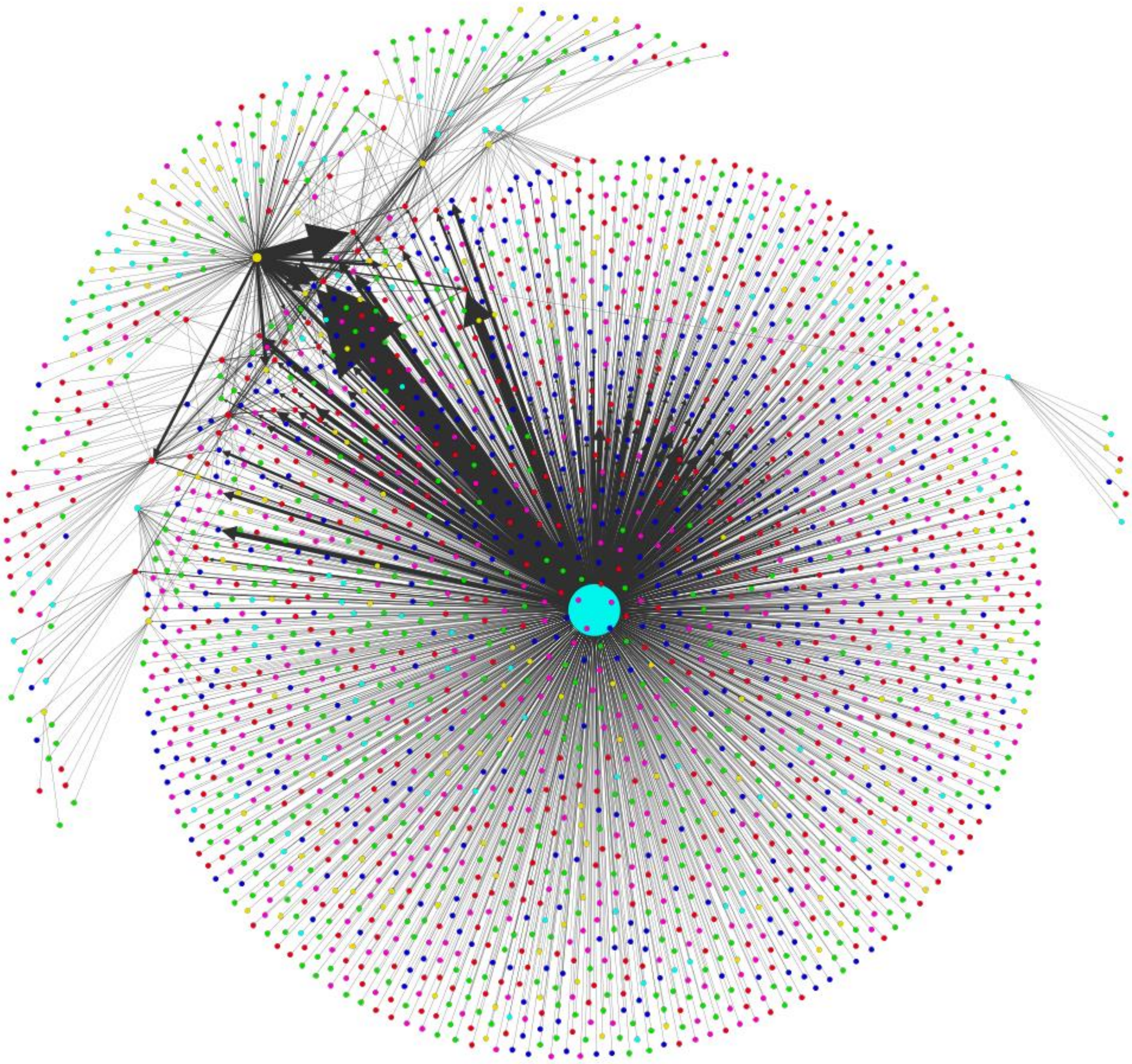

Table c1: Top 10 In-Degree Centrality Entire Funding Network

Actor	Position	Kind	**In-Degree**	Out-Degree	Closeness	Betweenness	Eigenvector
UNITN	LOC	UNI	**165**	2	1,000	52	0,977
FBK	LOC	RES	**140**	6	0,800	196	0,894
INFORMATICA TRENTINA	LOC	RES	**64**	13	0,392	68	1,000
CREATE-NET	LOC	RES	**62**	0	0,000	0	0,360
ENGINSOFT	LOC	IND	**29**	0	0,000	0	0,064
PAT	LOC	PUB	**28**	415	0,616	4.008	0,189
CNRS	INT	RES	**27**	0	0,000	0	0,026
TRENTO RISE	LOC	RES	**25**	39	0,360	2.060	0,245
ENGINEERING	NAT	IND	**24**	5	0,632	18	0,115
GRAPHITECH	LOC	RES	**22**	0	0,000	0	0,073

Table c2: Top 10 Out-Degree Centrality Entire Funding Network

Actor	Position	Kind	In-Degree	**Out-Degree**	Closeness	Betweenness	Eigenvector
EU	INT	DIF	0	**4130**	0,921	0	0,000
PAT	LOC	PUB	28	**415**	0,616	4.008	0,189
MINISTRY OF ECONOMIC DEVELOPMENT	NAT	PUB	3	**70**	0,443	610	0,020
EIT ICT LABS	INT	RES	5	**58**	0,499	2.103	0,027
TRENTO RISE	LOC	RES	25	**39**	0,360	2.060	0,245
ARTEMIS INDUSTRY ASSOCIATION	INT	DIF	0	**29**	0,787	0	0,000
CNR	NAT	RES	2	**25**	0,279	6	0,002
MINISTRY OF EDUCATION UNIVERSITY AND RESEARCH	NAT	PUB	0	**25**	0,844	0	0,000
EURISCE	LOC	RES	6	**18**	0,217	304	0,007
EUROPEAN REGIONAL DEVELOPMENT FUND	INT	DIF	0	**16**	0,392	0	0,000

Table c3: Top 10 Betweenness Centrality Entire Funding Network

Actor	Position	Kind	In-Degree	Out-Degree	Closeness	**Betweenness**	Eigenvector
PAT	LOC	PUB	28	415	0,616	**4.008**	0,189
EIT ICT LABS	INT	RES	5	58	0,499	**2.103**	0,027
TRENTO RISE	LOC	RES	25	39	0,360	**2.060**	0,245
MINISTRY OF ECONOMIC DEVELOPMENT	NAT	PUB	3	70	0,443	**610**	0,020
LIBON	INT	DIF	1	2	0,266	**565**	0,002

EURISCE	LOC	RES	6	18	0,217	**304**	0,007
DISTRETTO TECN TRENTINO	LOC	RES	14	4	0,384	**290**	0,071
FBK	LOC	RES	140	6	0,800	**196**	0,894
REGIONE PIEMONDE	NAT	PUB	3	12	1,000	**188**	0,006
TELECOM ITALIA	NAT	IND	12	5	0,273	**142**	0,022

Table c4: Top 10 Closeness Centrality Entire Funding Network

Actor	Position	Kind	In-Degree	Out-Degree	**Closeness**	Betweenness	Eigenvector
REGIONE PIEMONDE	NAT	PUB	3	12	**1,000**	188	0,006
UNITN	LOC	UNI	165	2	**1,000**	52	0,977
REGIONE TOSCANA	NAT	PUB	3	3	**1,000**	40	0,006
EC SOUTH EAST EUROPE	INT	DIF	0	10	**1,000**	0	0,000
REGIONE PUGLIA	NAT	PUB	0	4	**1,000**	0	0,000
EUROPEAN DATA NETWORK	INT	DIF	0	3	**1,000**	0	0,000
REGIONE VENETO	NAT	PUB	0	2	**1,000**	0	0,000
EU	INT	DIF	0	4130	**0,921**	0	0,000
MINISTRY OF EDUCATION UNIVERSITY AND RESEARCH	NAT	PUB	0	25	**0,844**	0	0,000
FBK	LOC	RES	140	6	**0,800**	196	0,894

Table c5: Top 10 Eigenvector Centrality Entire Funding Network

Actor	Position	Kind	In-Degree	Out-Degree	Closeness	Betweenness	**Eigenvector**
INFORMATICA TRENTINA	LOC	RES	64	13	0,392	68	**1,000**
UNITN	LOC	UNI	165	2	1,000	52	**0,977**
FBK	LOC	RES	140	6	0,800	196	**0,894**
CREATE-NET	LOC	RES	62	0	0,000	0	**0,360**
CONSORZIO COMUNI TRENTINI	LOC	PUB	17	0	0,000	0	**0,262**
TRENTINO NETWORK	LOC	PUB	18	12	0,386	71	**0,260**
TRENTO RISE	LOC	RES	25	39	0,360	2.060	**0,245**
APSS	LOC	PUB	16	0	0,000	0	**0,225**
LABORATORY OF APPLIED ONTOLOGY	LOC	RES	21	0	0,000	0	**0,207**
PAT	LOC	PUB	28	415	0,616	4.008	**0,189**

Figure 21a: Local Trentino ICT Collaboration Network (2000-2014)

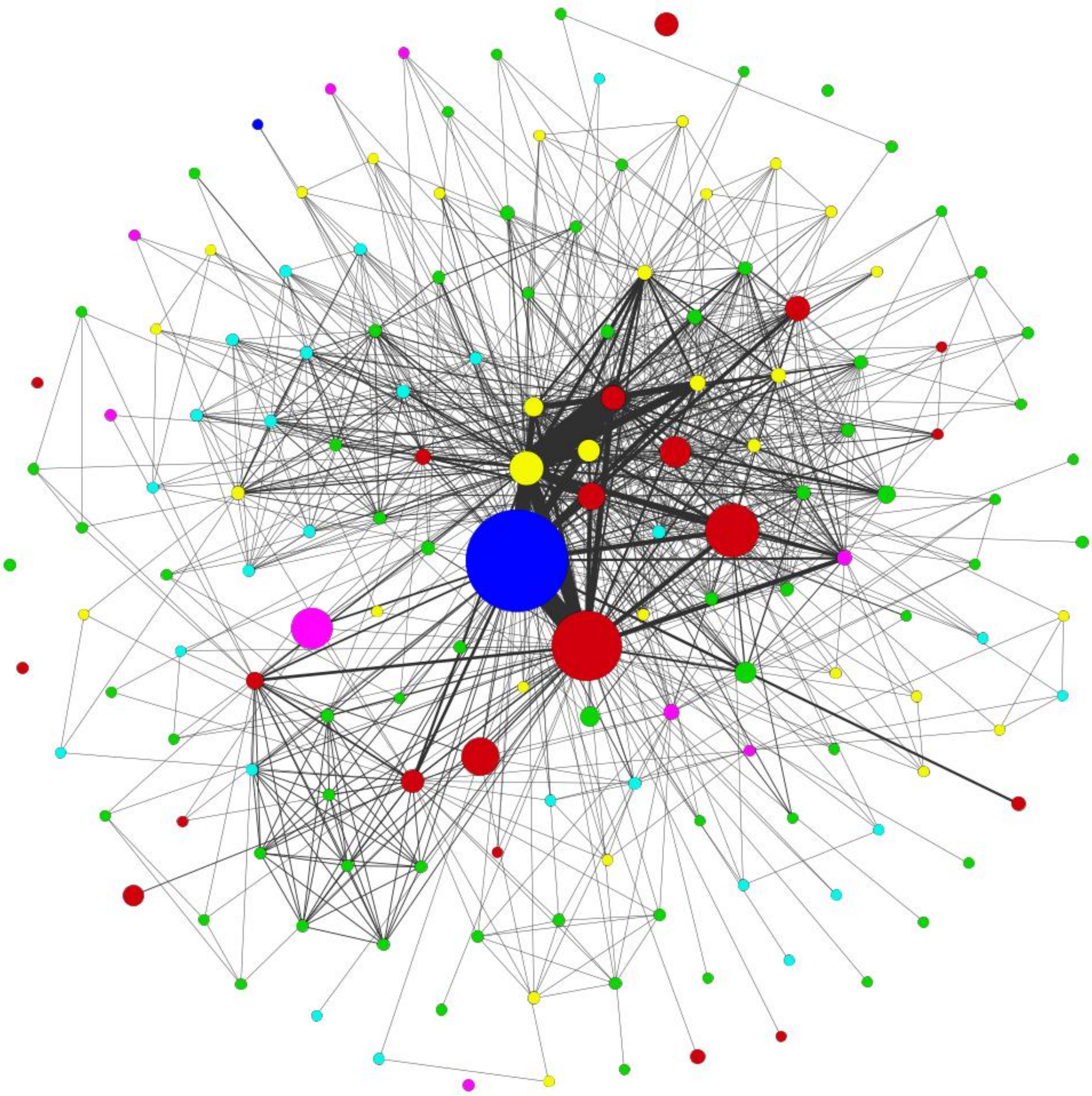

Table d1: Top 10 Degree Centrality Local Collaboration Network

Actor	Kind	**Degree**	Closeness	Betweenness	Normalized Betweennes s	Eigenvector
PAT	PUB	**335**	0,735	3.421	0,283	1,000
UNITN	UNI	**245**	0,661	1.761	0,146	0,774
INFORMATICA TRENTINA	RES	**233**	0,658	1.475	0,122	0,818
FBK	RES	**227**	0,676	3.086	0,255	0,712
TRENTO RISE	RES	**117**	0,605	503	0,042	0,345
TRENTINO NETWORK	PUB	**103**	0,593	321	0,027	0,307
APSS	PUB	**95**	0,566	162	0,013	0,339
CONSORZIO DEI COMUNI TRENTINI	PUB	**93**	0,558	56	0,005	0,376
CREATE-NET	RES	**91**	0,584	425	0,035	0,273
COMUNE DI TRENTO	PUB	**72**	0,551	38	0,003	0,244

Table d2: Top 10 Betweenness Centrality Local Collaboration Network

Actor	Kind	Degree	Closeness	**Betweennes s**	Normalized Betweenness	Eigenvector
PAT	PUB	335	0,735	**3.421**	0,283	1,000
FBK	RES	227	0,676	**3.086**	0,255	0,712
UNITN	UNI	245	0,661	**1.761**	0,146	0,774
INFORMATICA TRENTINA	RES	233	0,658	**1.475**	0,122	0,818
TRENTO RISE	RES	117	0,605	**503**	0,042	0,345
FONDAZIONE EDMUND MACH	RES	17	0,510	**446**	0,037	0,051
CREATE-NET	RES	91	0,584	**425**	0,035	0,273
GRAPHITECH	RES	45	0,545	**388**	0,032	0,114
DISTRETTO TECNOLOGICO TRENTINO	RES	51	0,538	**367**	0,03	0,112
CNR-IVALSA	RES	44	0,526	**348**	0,029	0,098

Table d3: Top 10 Closeness Centrality Local Collaboration Network

Actor	Kind	Degree	**Closeness**	Betweenness	Normalized Betweenness	Eigenvector
PAT	PUB	335	**0,735**	3.421	0,283	1,000
FBK	RES	227	**0,676**	3.086	0,255	0,712
UNITN	UNI	245	**0,661**	1.761	0,146	0,774
INFORMATICA TRENTINA	RES	233	**0,658**	1.475	0,122	0,818
TRENTO RISE	RES	117	**0,605**	503	0,042	0,345
TRENTINO NETWORK	PUB	103	**0,593**	321	0,027	0,307
CREATE-NET	RES	91	**0,584**	425	0,035	0,273
APSS	PUB	95	**0,566**	162	0,013	0,339
CONSORZIO DEI COMUNI TRENTINI	PUB	93	**0,558**	56	0,005	0,376
COMUNE DI TRENTO	PUB	72	**0,551**	38	0,003	0,244

Table d4: Top 10 Eigenvector Centrality Entire Collaboration Network

Actor	Kind	Degree	Closeness	Betweenness	Normalized Betweenness	**Eigenvector**
PAT	PUB	335	0,735	3.421	0,283	**1,000**
INFORMATICA TRENTINA	RES	233	0,658	1.475	0,122	**0,818**
UNITN	UNI	245	0,661	1.761	0,146	**0,774**
FBK	RES	227	0,676	3.086	0,255	**0,712**
CONSORZIO DEI COMUNI TRENTINI	PUB	93	0,558	56	0,005	**0,376**
TRENTO RISE	RES	117	0,605	503	0,042	**0,345**
APSS	PUB	95	0,566	162	0,013	**0,339**
TRENTINO NETWORK	PUB	103	0,593	321	0,027	**0,307**
CREATE-NET	RES	91	0,584	425	0,035	**0,273**
COMUNE DI TRENTO	PUB	72	0,551	38	0,003	**0,244**

Figure 21b: Local Trentino ICT Coordination Network (2000-2014)

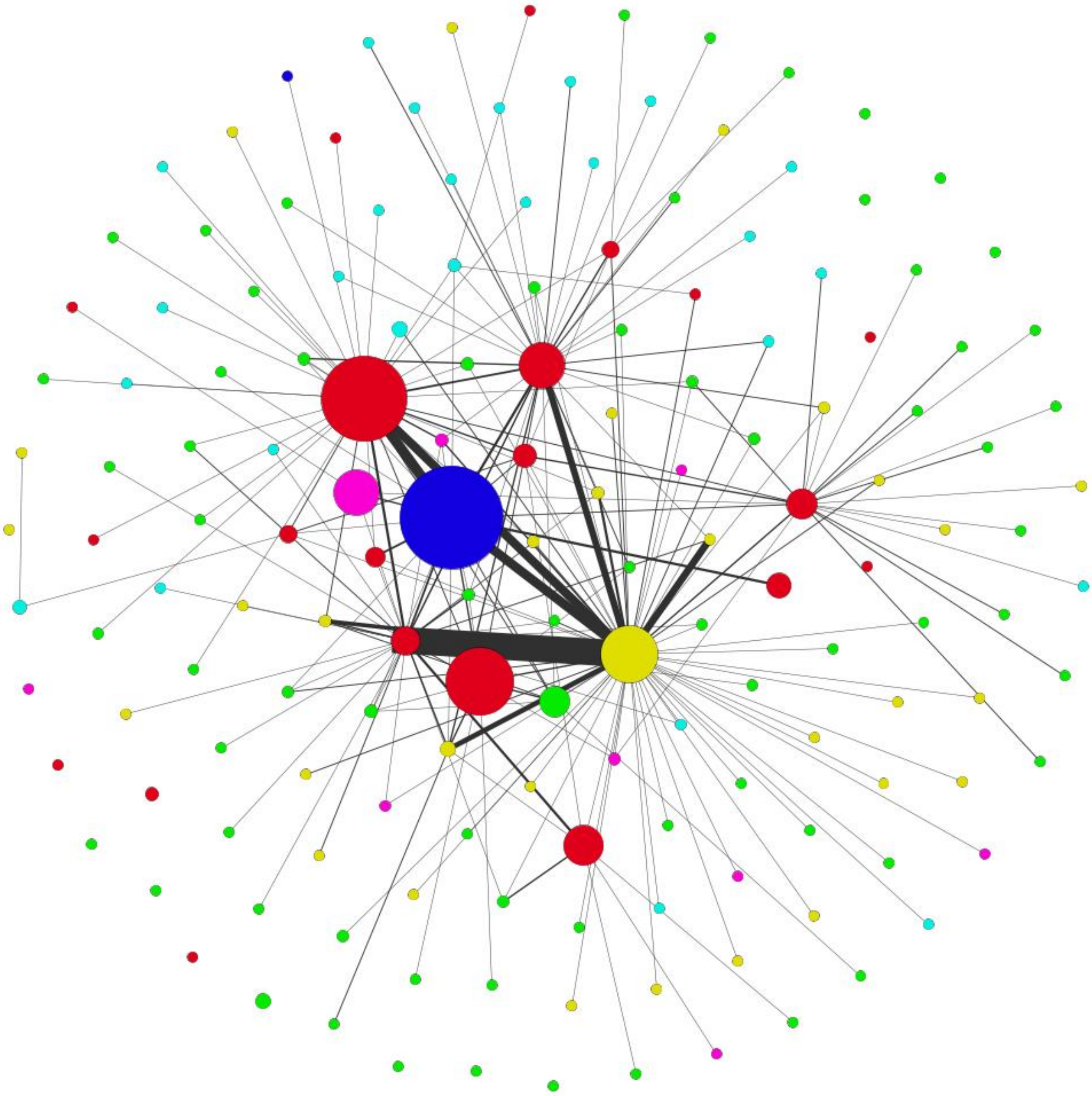

Table e1: Top 10 Degree Centrality Local Coordination Network

Actor	Kind	**Degree**	Closeness	Betweenness	Normalized Betweenness	Eigenvector
PAT	PUB	**207**	0,635	5.473	0,453	1,000
INFORMATICA TRENTINA	RES	**106**	0,519	1.718	0,142	0,827
FBK	RES	**88**	0,563	2.472	0,204	0,466
UNITN	UNI	**77**	0,525	743	0,061	0,469
TRENTO RISE	RES	**69**	0,527	2.176	0,18	0,301
DISTRETTO TECNOLOGICO TRENTINO	RES	**36**	0,471	1.859	0,154	0,076
CREATE-NET	RES	**24**	0,479	319	0,026	0,117
TRENTINO NETWORK	PUB	**23**	0,448	148	0,012	0,197
CONSORZIO DEI COMUNI TRENTINI	PUB	**17**	0,432	0	0	0,218
APSS	PUB	**15**	0,436	2	0	0,158

Table e2: Top 10 Betweenness Centrality Local Coordination Network

Actor	Kind	Degree	Closeness	**Betweenness**	Normalized Betweenness	Eigenvector
PAT	PUB	207	0,635	**5.473**	0,453	1,000
FBK	RES	88	0,563	**2.472**	0,204	0,466
TRENTO RISE	RES	69	0,527	**2.176**	0,18	0,301
DISTRETTO TECNOLOGICO TRENTINO	RES	36	0,471	**1.859**	0,154	0,076
INFORMATICA TRENTINA	RES	106	0,519	**1.718**	0,142	0,827
UNITN	UNI	77	0,525	**743**	0,061	0,469
GRAPHITECH	RES	14	0,419	**413**	0,034	0,075
TRENTINO SVILLUPO	RES	10	0,447	**412**	0,034	0,048
CREATE-NET	RES	24	0,479	**319**	0,026	0,117
FONDAZIONE EDMUND MACH	RES	7	0,429	**274**	0,023	0,035

Table e3: Top 10 Closeness Centrality Local Coordination Network

Actor	Kind	Degree	**Closeness**	Betweenness	Normalized Betweenness	Eigenvector
PAT	PUB	207	**0,635**	5.473	0,453	1,000
FBK	RES	88	**0,563**	2.472	0,204	0,466
TRENTO RISE	RES	69	**0,527**	2.176	0,18	0,301
UNITN	UNI	77	**0,525**	743	0,061	0,469
INFORMATICA TRENTINA	RES	106	**0,519**	1.718	0,142	0,827
CREATE-NET	RES	24	**0,479**	319	0,026	0,117
DISTRETTO TECNOLOGICO TRENTINO	RES	36	**0,471**	1.859	0,154	0,076
GPI GROUPPO	IND	9	**0,460**	0	0	0,083
CNR-IVALSA	RES	13	**0,459**	88	0,007	0,053
COMUNE DI TRENTO	PUB	8	**0,456**	0	0	0,090

Table e4: Top 10 Eigenvector Centrality Entire Collaboration Network

Actor	Kind	Degree	Closeness	Betweenness	Normalized Betweenness	**Eigenvector**
PAT	PUB	207	0,635	5.473	0,453	**1,000**
INFORMATICA TRENTINA	RES	106	0,519	1.718	0,142	**0,827**
UNITN	UNI	77	0,525	743	0,061	**0,469**
FBK	RES	88	0,563	2.472	0,204	**0,466**
TRENTO RISE	RES	69	0,527	2.176	0,18	**0,301**
CONSORZIO DEI COMUNI TRENTINI	PUB	17	0,432	0	0	**0,218**
TRENTINO NETWORK	PUB	23	0,448	148	0,012	**0,197**
APSS	PUB	15	0,436	2	0	**0,158**
CREATE-NET	RES	24	0,479	319	0,026	**0,117**
COMUNE DI TRENTO	PUB	8	0,456	0	0	**0,090**

Figure 21c: Local Trentino ICT Funding Network (2000-2014)

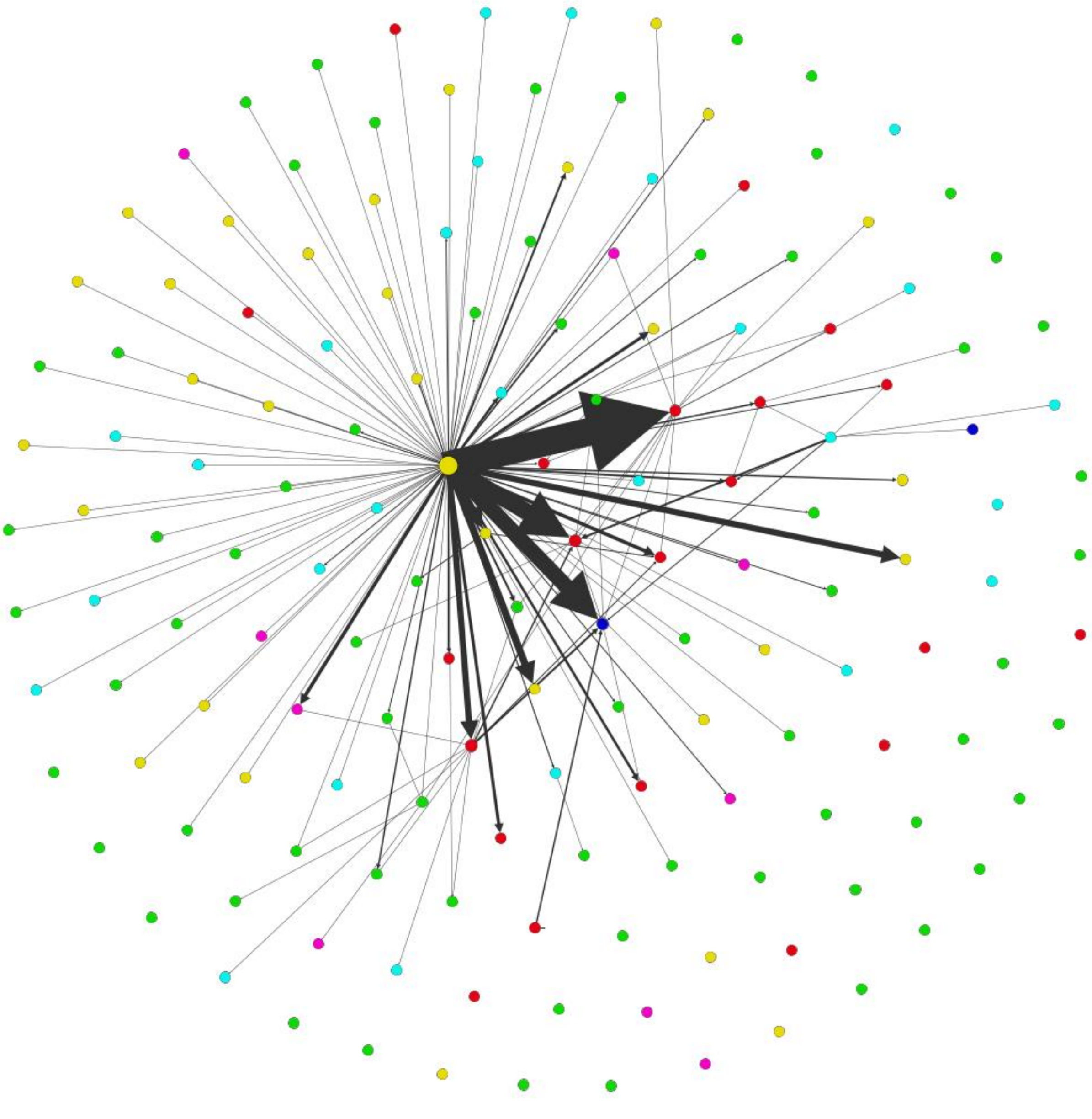

Table f1: Top 10 In-Degree Centrality Local Funding Network

Actor	Kind	**In-Degree**	Out-Degree	Closeness	Betweenness	Eigenvector
INFORMATICA TRENTINA	RES	**55**	13	0,522	21,975	1,000
UNITN	UNI	**42**	1	1,000	5,167	0,840
FBK	RES	**41**	2	0,750	8,000	0,774
CONSORZIO DEI COMUNI TRENTINI	PUB	**14**	0	0,000	0,000	0,259
TRENTINO NETWORK	PUB	**14**	6	0,489	5,000	0,259
APSS	PUB	**12**	0	0,000	0,000	0,222
CREATE-NET	RES	**12**	0	0,000	0,000	0,329
TRENTO RISE	RES	**12**	16	0,857	12,000	0,222
GPI GROUPPO	IND	**8**	0	0,000	0,000	0,153
CNR-IVALSA	RES	**7**	0	0,000	0,000	0,083

Table f2: Top 10 Out-Degree Centrality Local Funding Network

Actor	Kind	In-Degree	**Out-Degree**	Closeness	Betweenness	Eigenvector
PAT	PUB	6	**329**	0,923	503,582	0,180
TRENTO RISE	RES	12	**16**	0,857	12,000	0,222
INFORMATICA TRENTINA	RES	55	**13**	0,522	21,975	10,000
CASSA DI RISPARMIO DI TRENTO E ROVERETO	DIF	0	**12**	0,345	0,000	0,000
TRENTINO NETWORK	PUB	14	**6**	0,489	5,000	0,259
SAYSERVICE	SME	4	**5**	0,778	0,276	0,074
TRENTINO RISCOSSIONI	SME	0	**5**	0,500	0,000	0,000
EURICSE	RES	1	**4**	0,667	0,000	0,001
DISTRETTO TECNOLOGICO TRENTINO	RES	4	**3**	0,489	106,000	0,057
FBK	RES	41	**2**	0,750	8,000	0,774

Table f3: Top 8 Betweenness Centrality Local Funding Network

Actor	Kind	In-Degree	Out-Degree	Closeness	**Betweenness**	Eigenvector
PAT	PUB	6	329	0,923	**503,582**	0,180
DISTRETTO TECNOLOGICO TRENTINO	RES	4	3	0,489	**106,000**	0,057
INFORMATICA TRENTINA	RES	55	13	0,522	**21,975**	1,000
TRENTO RISE	RES	12	16	0,857	**12,000**	0,222
FBK	RES	41	2	0,750	**8,000**	0,774
UNITN	UNI	42	1	1,000	**5,167**	0,840
TRENTINO NETWORK	PUB	14	6	0,489	**5,000**	0,259
SAYSERVICE	SME	4	5	0,778	**0,276**	0,074

Table f4: Top 10 Closeness Centrality Local Funding Network

Actor	Kind	In-Degree	Out-Degree	**Closeness**	Betweenness	Eigenvector
UNITN	UNI	42	1	**1,000**	5,167	0,840
PAT	PUB	6	329	**0,923**	503,582	0,180
TRENTO RISE	RES	12	16	**0,857**	12,000	0,222
SAYSERVICE	SME	4	5	**0,778**	0,276	0,074
FBK	RES	41	2	**0,750**	8,000	0,774
EURICSE	RES	1	4	**0,667**	0,000	0,001
INFORMATICA TRENTINA	RES	55	13	**0,522**	21,975	1,000
TRENTINO RISCOSSIONI	SME	0	5	**0,500**	0,000	0,000
TRENTINO NETWORK	PUB	14	6	**0,489**	5,000	0,259
DISTRETTO TECNOLOGICO TRENTINO	RES	4	3	**0,489**	106,000	0,057

Table f5: Top 10 Eigenvector Centrality Entire Funding Network

Actor	Kind	In-Degree	Out-Degree	Closeness	Betweenness	**Eigenvector**
INFORMATICA TRENTINA	RES	55	13	0,522	21,975	**1,000**
UNITN	UNI	42	1	1,000	5,167	**0,840**
FBK	RES	41	2	0,750	8,000	**0,774**
CREATE-NET	RES	12	0	0,000	0,000	**0,329**
TRENTINO NETWORK	PUB	14	6	0,489	5,000	**0,259**
CONSORZIO DEI COMUNI TRENTINI	PUB	14	0	0,000	0,000	**0,259**
TRENTO RISE	RES	12	16	0,857	12,000	**0,222**
APSS	PUB	12	0	0,000	0,000	**0,222**
ALGORAB	SME	6	0	0,000	0,000	**0,197**
PAT	PUB	6	329	0,923	503,582	**0,180**

Figure 22a: Collaboration Ego-Network of the Local University in Trentino (2000-2014)

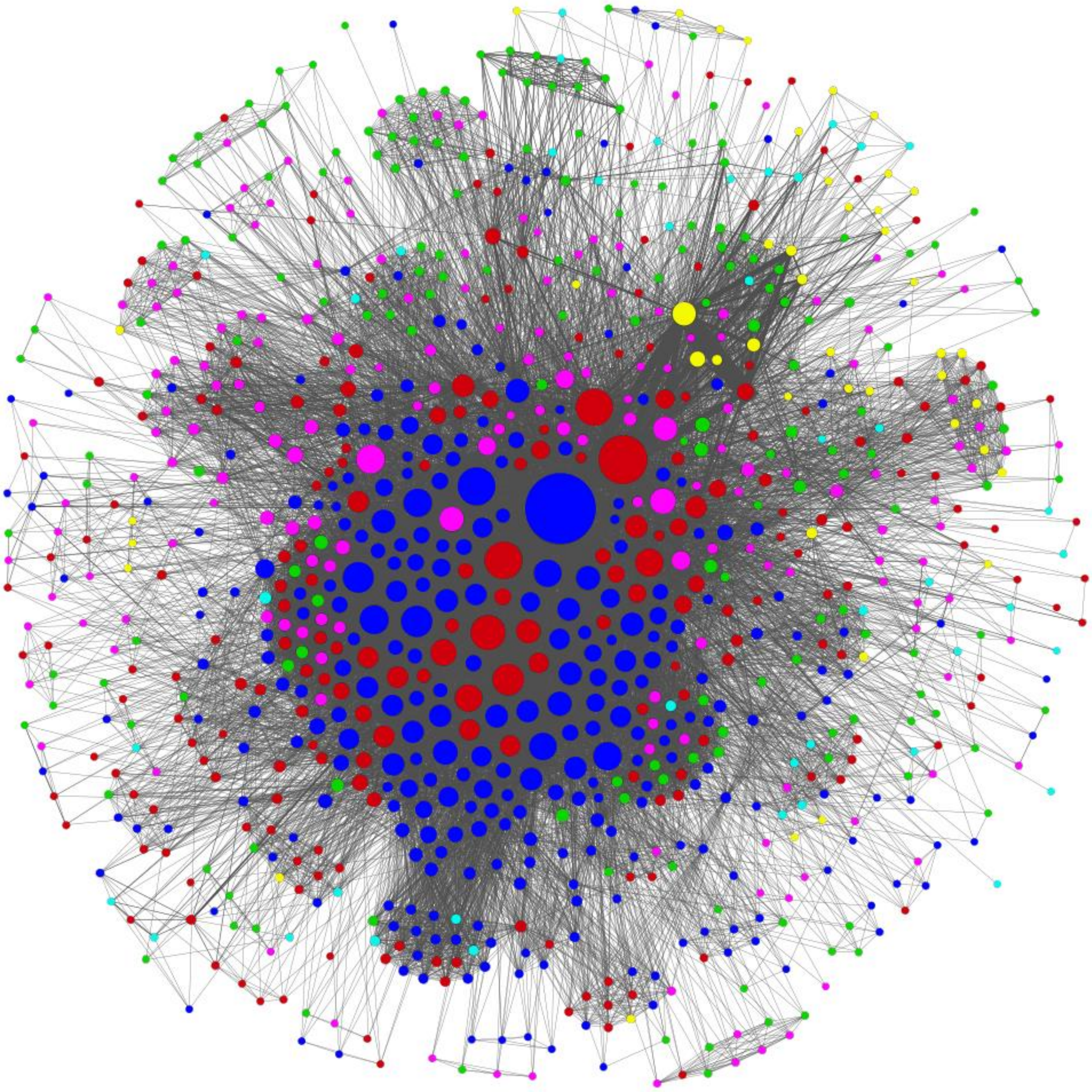

Figure 22b: Collaboration Ego-Network of the Biggest Research Center in Trentino (2000-2014)

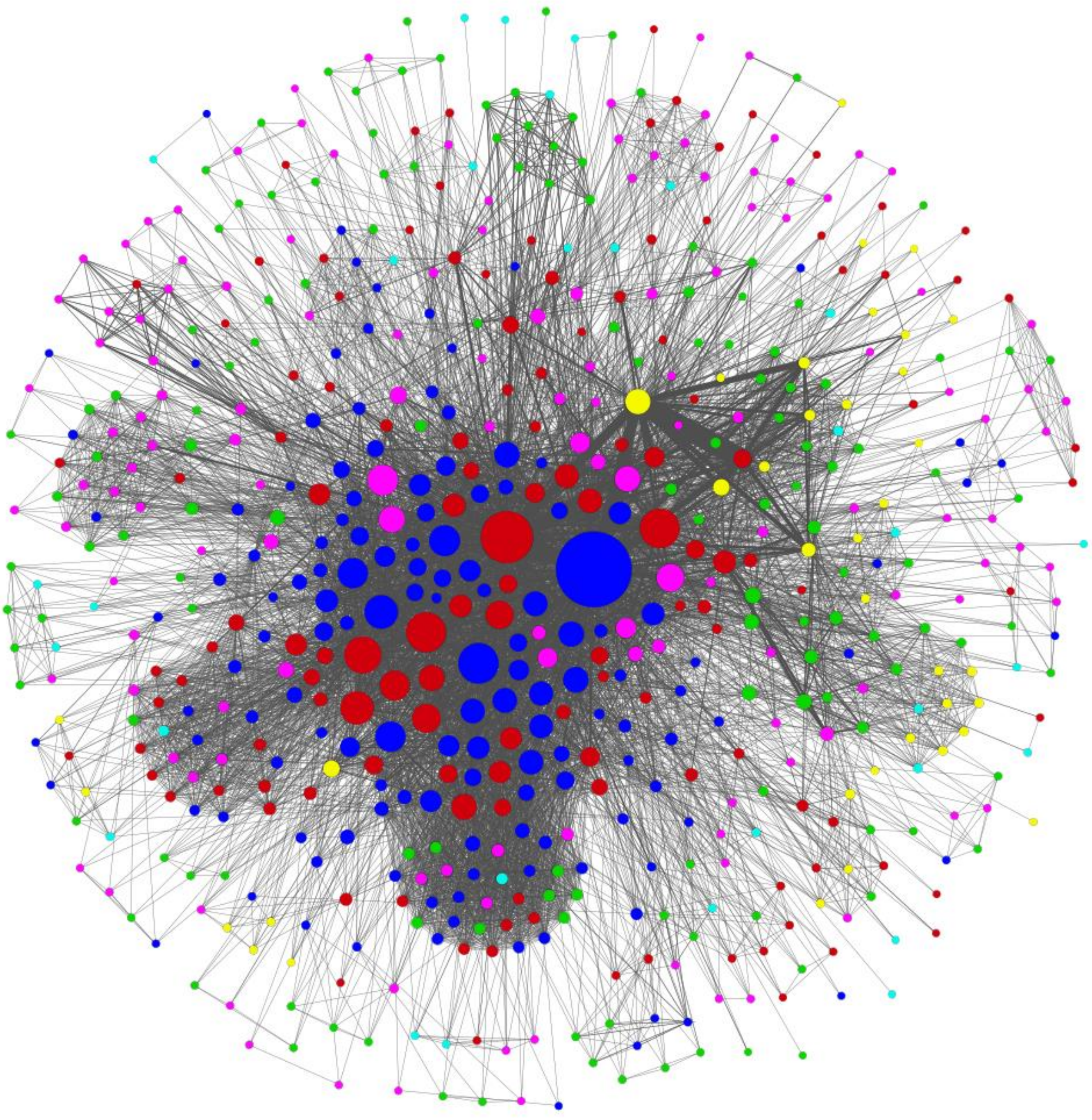

Figure 22c: Collaboration Ego-Network of the Local Government body in Trentino (2000-2014)

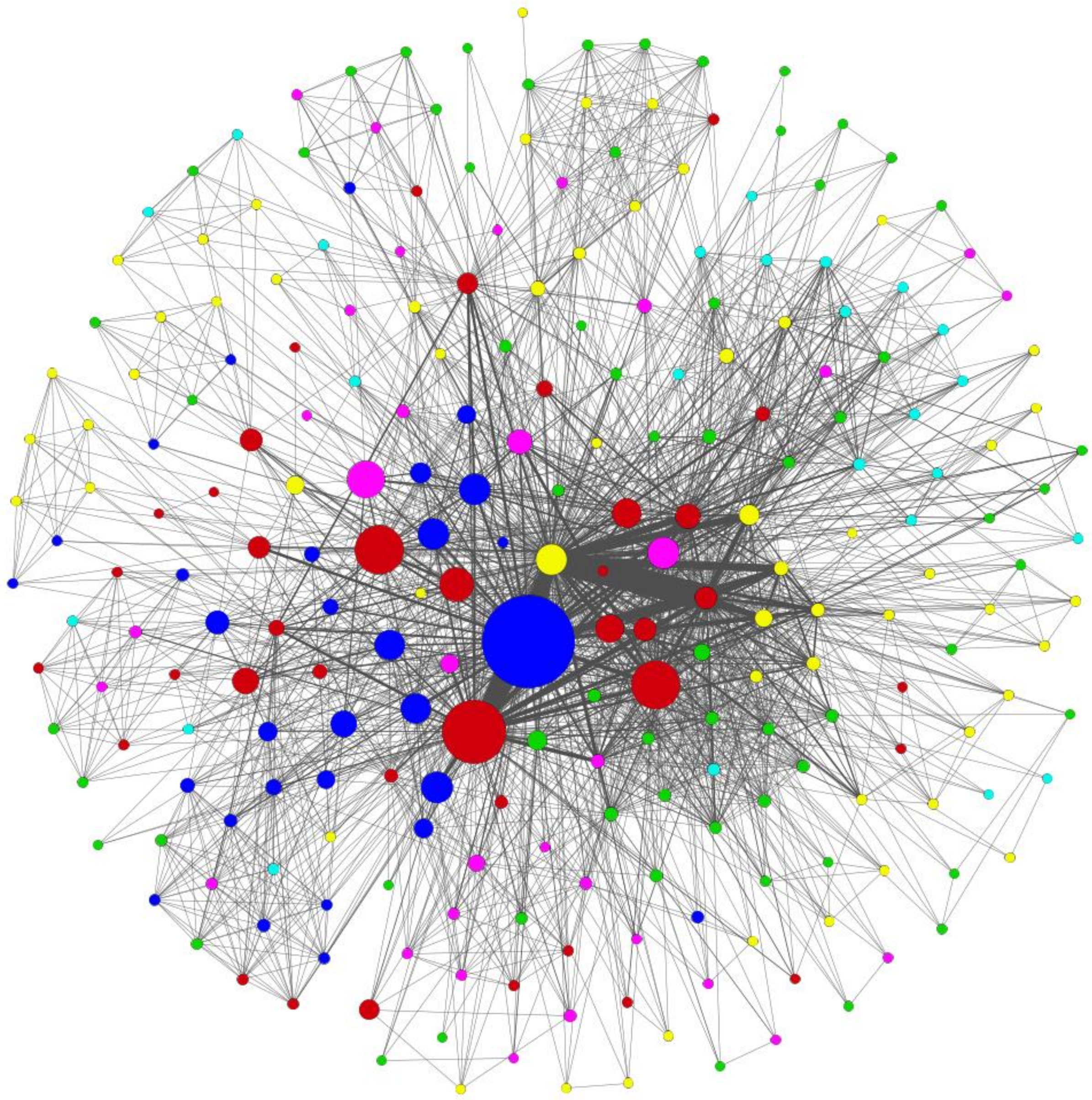

Figure 23a: Coordination Ego-Network of the Local University in Trentino (2000-2014)

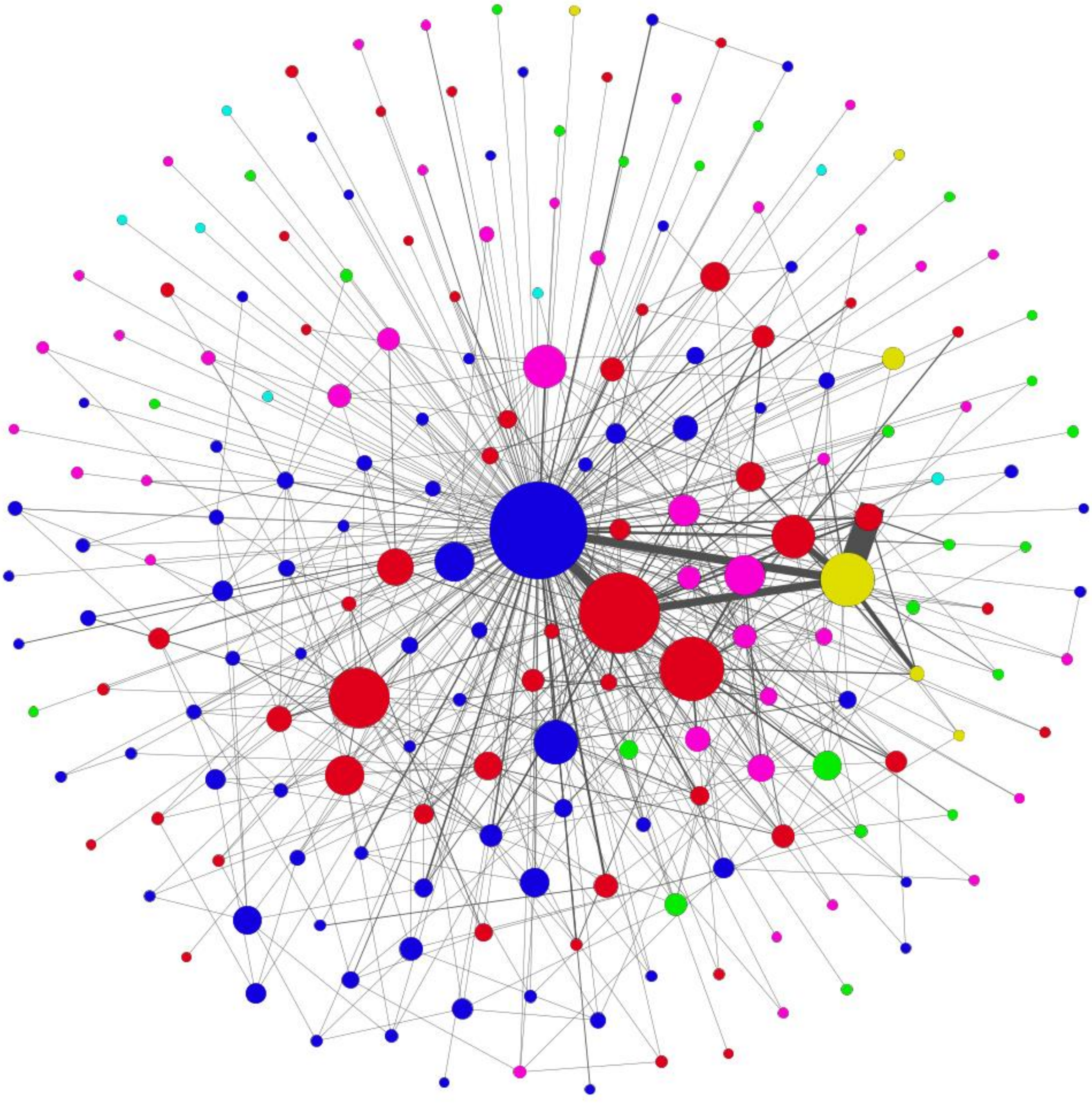

Figure 23b: Coordination Ego-Network of the Biggest Local Research Center in Trentino (2000-2014)

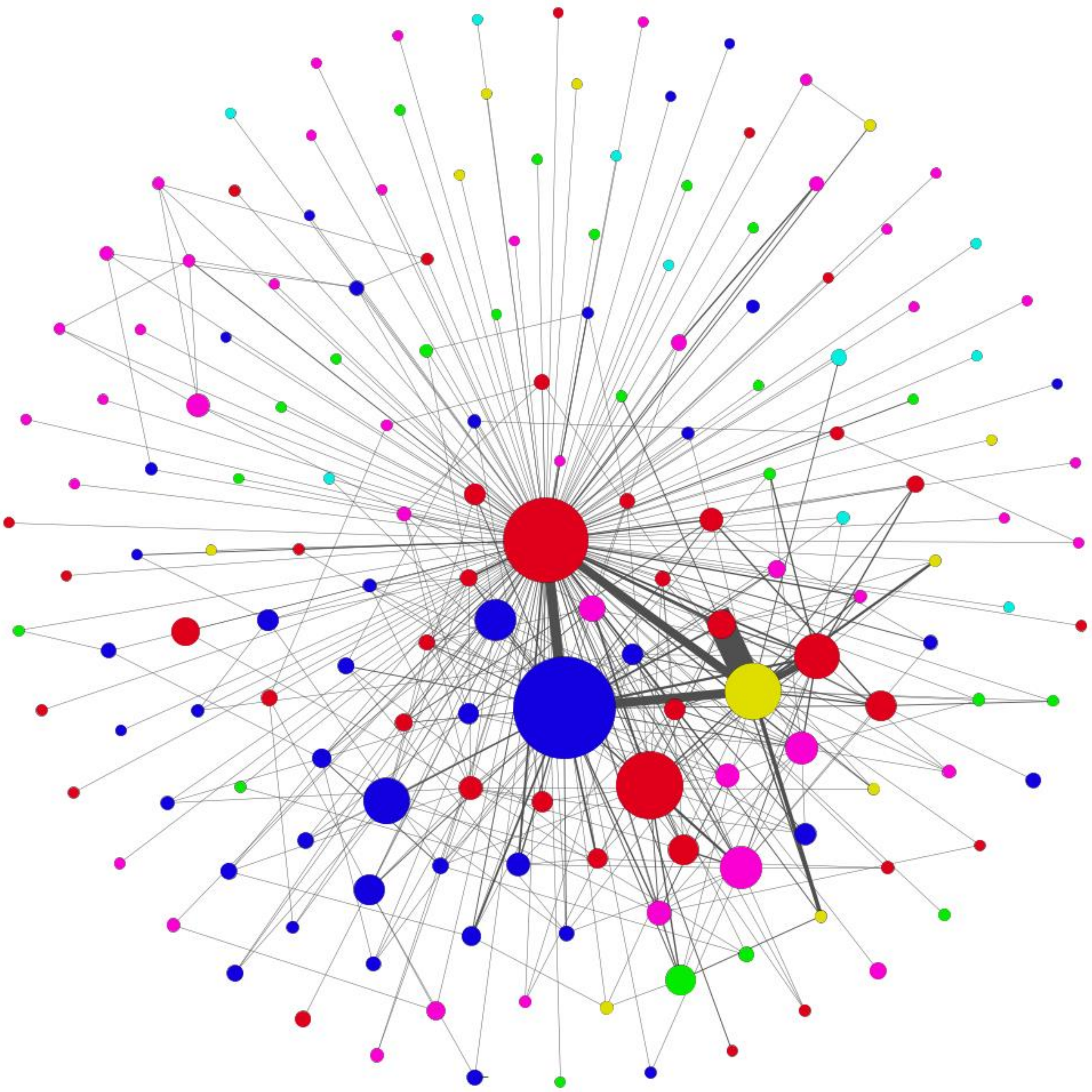

Figure 23c: Coordination Ego-Network of the Local Government Body in Trentino (2000-2014)

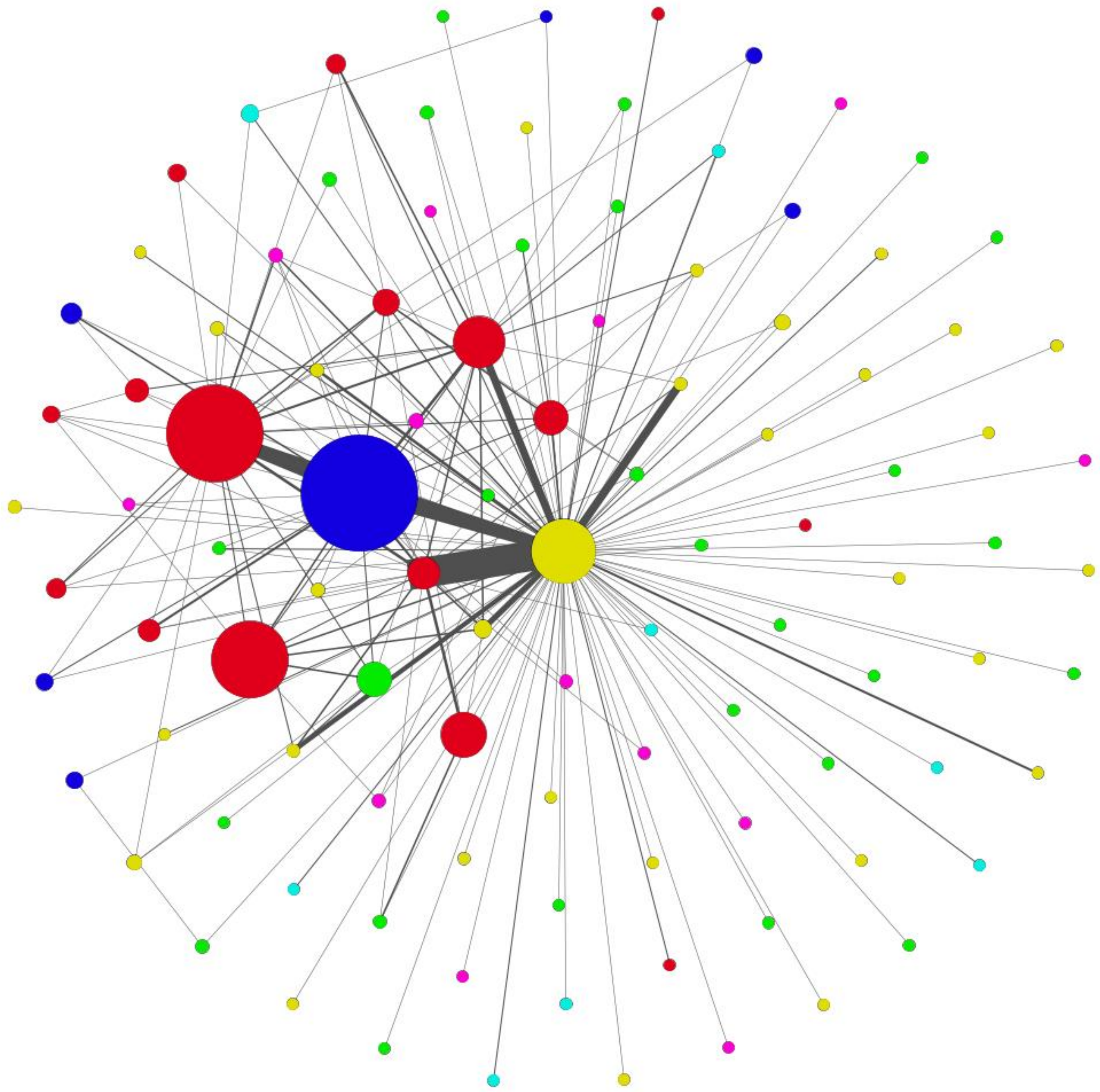

Figure 24a: Funding Ego-Network of the Local University in Trentino (2000-2014)

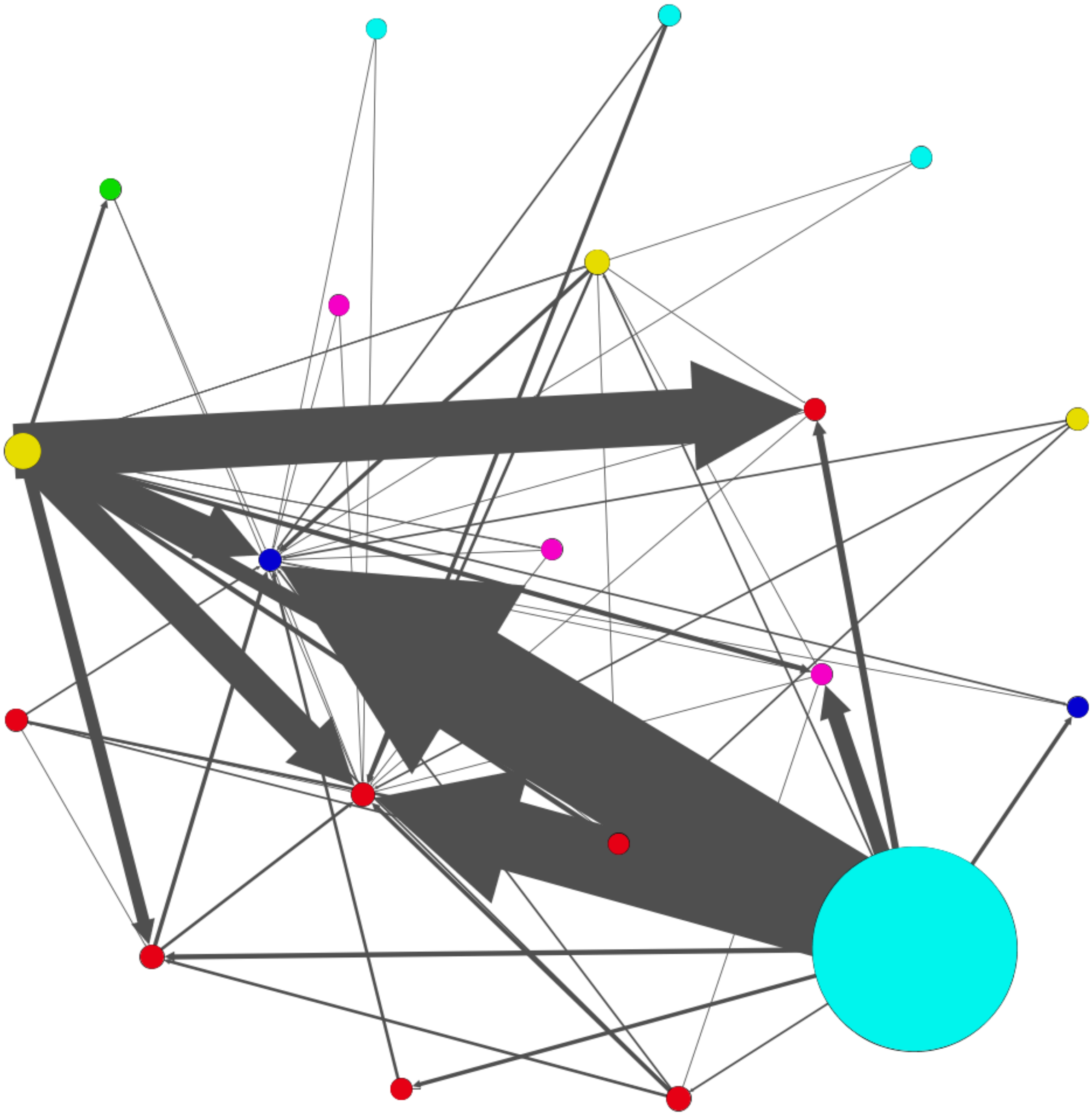

Figure 24b: Funding Ego-Network of the Biggest Research Center in Trentino (2000-2014)

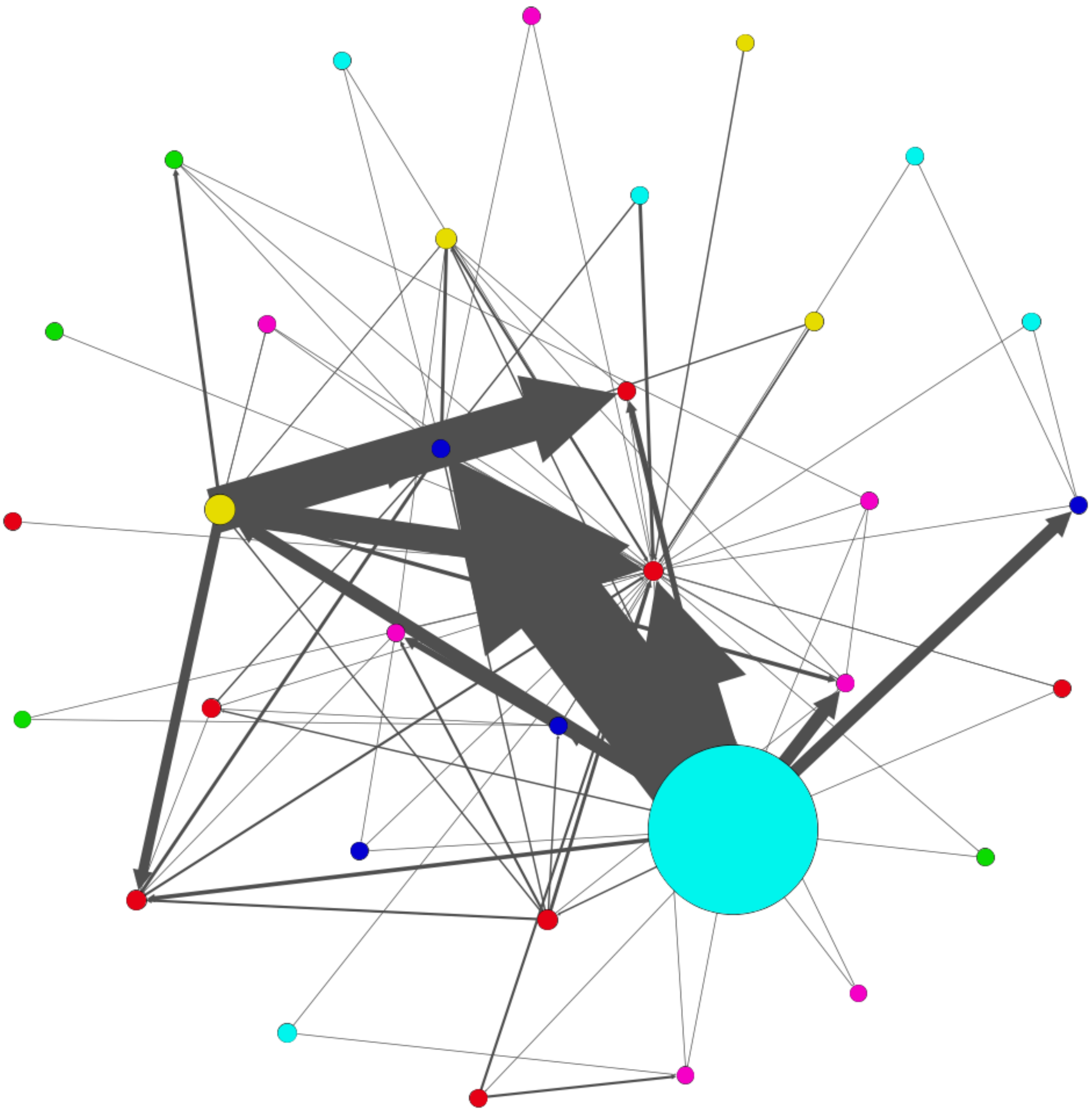

Figure 24c: Funding Ego-Network of the Local Government in Trentino (2000-2014)

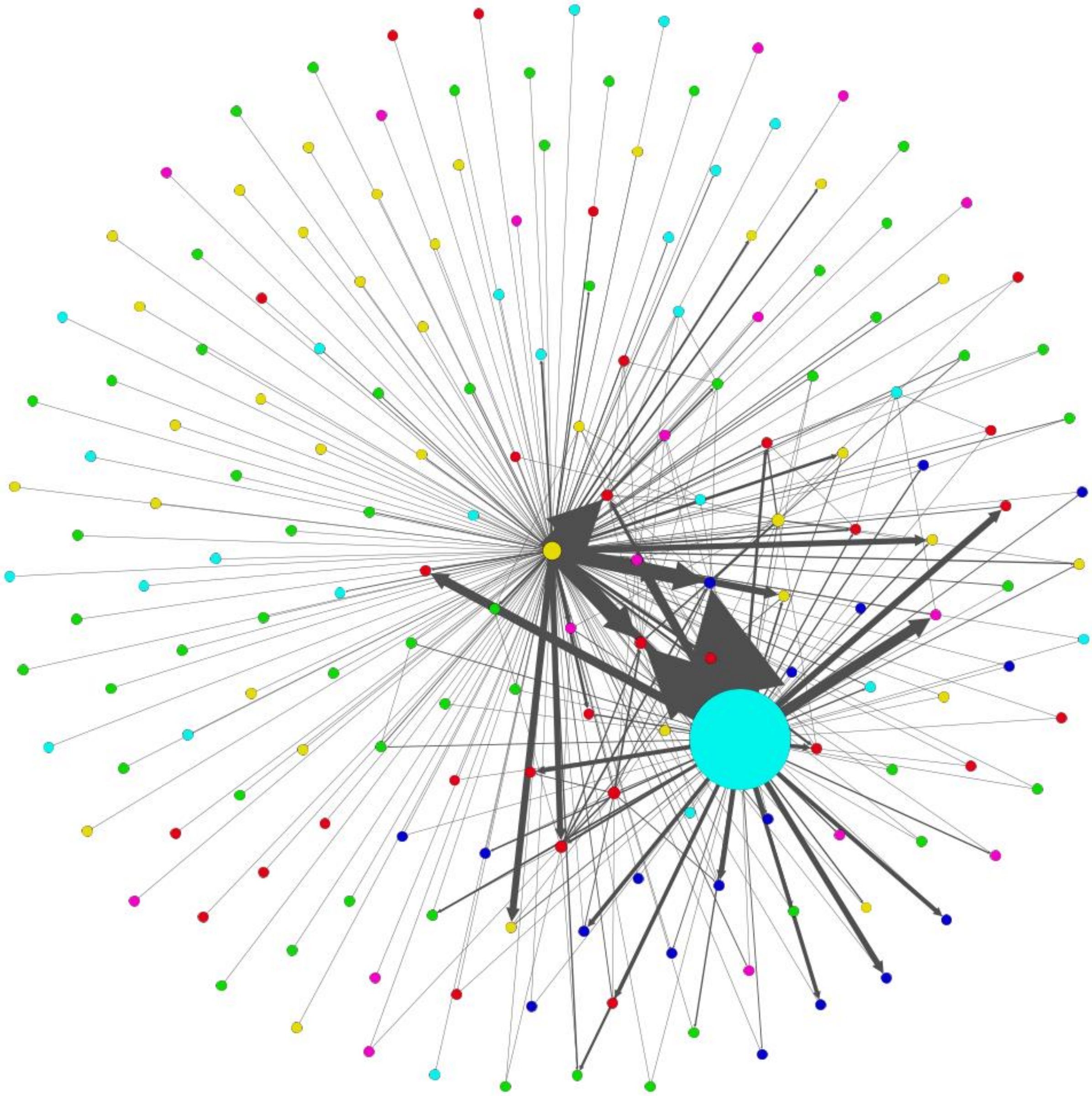

Table g1: Robustness check for the effect of geographical, institutional, and organizational proximities to the repeated collaboration ties (Model Version 1, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)				
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**
(Intercept)	0.01596 (0.00000)	0.01581 (0.00000)	0.01580 (0.00000)	0.01399 (0.00000)
Coordination (p-value)	1.33009*** (0.00100)	1.32953*** (0.00100)	1.32953*** (0.00100)	1.32930*** (0.00100)
Funding (p-value)	-0.00588*** (0.00100)	-0.00596*** (0.00100)	-0.00596*** (0.00100)	-0.00596*** (0.00100)
Geographical Proximity (GEOPROX) (p-value)		0.03430*** (0.00100)	0.03386*** (0.00100)	0.03334*** (0.00100)
Institutional Proximity (INSTPROX) (p-value)			0.00044 (0.38162)	0.00032 (0.41359)
Organizational Proximity (ORGPROX) (p-value)				0.00911*** (0.00100)
R^2 (Adj)	0.22644 (0.22644)	0.22663 (0.22663)	0.22663 (0.22663)	0.22714 (0.22714)
Observations (actors)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1

The statistical analysis was performed with UCInet (Borgatti et al, 2002)

Table g2: Robustness check for the analytical effect of organizationally proximate actors to the strong collaboration ties (Model Version 2, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)						
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**	**Coefficients (4 controls)**	**Coefficients (5 controls)**
(Intercept)	0.01596 (0.00000)	0.01410 (0.00000)	0.01376 (0.00000)	0.01379 (0.00000)	0.01415 (0.00000)	0.01413 (0.00000)
Coordination (p-value)	1.33009*** (0.00100)	1.32905*** (0.00100)	1.32899*** (0.00100)	1.32900*** (0.00100)	1.32893*** (0.00100)	1.32891*** (0.00100)
Funding (p-value)	-0.00588*** (0.00100)	-0.00553*** (0.00100)	-0.00563*** (0.00100)	-0.00563*** (0.00100)	-0.00566*** (0.00100)	-0.00566*** (0.00100)
Both Universities (BOTHUNI) (p-value)		0.04643*** (0.00100)	0.04676*** (0.00100)	0.04674*** (0.00100)	0.04638*** (0.00100)	0.04639*** (0.00100)
Both Research Centers (BOTHRES) (p-value)			0.00620*** (0.00300)	0.00618*** (0.00200)	0.00581*** (0.00300)	0.00583*** (0.00400)
Both Large Firms (BOTHLF) (p-value)				-0.00059 (0.40060)	-0.00095 (0.66833)	-0.00093 (0.34166)
Both SMEs (BOTHSME) (p-value)					-0.00502*** (0.00100)	-0.00500*** (0.00200)
Both Public Agencies (BOTHPUB) (p-value)						0.00265 (0.19381)
R^2 (Adj)	0.22644 (0.22644)	0.22962 (0.22962)	0.22969 (0.22969)	0.22969 (0.22969)	0.22975 (0.22975)	0.22975 (0.22975)
Observations (actors)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1						
The statistical analysis was performed with UCInet (Borgatti et al, 2002)						

Table g3: Robustness check for the effect of cases where organizational proximity is absent on strong collaborative ties. The cases of combinations of Large Firms and other kinds of organizations (Model Version 3a, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)				
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**
(Intercept)	0.01596 (0.00000)	0.01413 (0.00000)	0.01464 (0.00000)	0.01426 (0.00000)
Coordination (p-value)	1.33009*** (0.00100)	1.32949*** (0.00100)	1.32950*** (0.00100)	1.32934*** (0.00100)
Funding (p-value)	-0.00588*** (0.00100)	-0.00559*** (0.00100)	-0.00544*** (0.00100)	-0.00555*** (0.00100)
Large Firms and Universities (LFUNI) (p-value)		0.02353*** (0.00100)	0.02738*** (0.00100)	0.04097*** (0.00100)
Large Firms and Research Centers (LFRES) (p-value)			0.00903*** (0.00100)	0.00159 (0.20979)
Large Firms and Public Agencies (LFPUB) (p-value)				-0.03795*** (0.00100)
R^2 (Adj)	0.22644 (0.22644)	0.22796 (0.22796)	0.22817 (0.22817)	0.22923 (0.22923)
Observations (actors)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1

The statistical analysis was performed with UCInet (Borgatti et al, 2002)

Table g4: Robustness check of the effect of cases where organizational proximity is absent on strong collaborative ties. The cases of combinations of SMEs and other kinds of organizations (Model Version 3b, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)				
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**
(Intercept)	0.01596 (0.00000)	0.01444 (0.00000)	0.01521 (0.00000)	0.01465 (0.00000)
Coordination (p-value)	1.33009*** (0.00100)	1.33001*** (0.00100)	1.32985*** (0.00100)	1.32938*** (0.00100)
Funding (p-value)	-0.00588*** (0.00100)	-0.00569*** (0.00100)	-0.00545*** (0.00100)	-0.00557*** (0.00100)
SMEs and Universities (SMEUNI) (p-value)		0.02353*** (0.00100)	0.02207*** (0.00100)	0.04002*** (0.00100)
SMEs and Research Centers (SMERES) (p-value)			0.01328*** (0.00100)	0.00077 (0.28172)
SMEs and Public Agencies (SMEPUB) (p-value)				-0.04257*** (0.00100)
R^2 (Adj)	0.22644 (0.22644)	0.22721 (0.22721)	0.22770 (0.22770)	0.22921 (0.22921)
Observations (actors)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1				
The statistical analysis was performed with UCInet (Borgatti et al, 2002)				

Table g5: Robustness check of the effect of relational proximity on the collaboration strong ties (Model Version 4, 2000-2014)

Dependent Variable: Collaboration Network Strong Ties (2000-2014)				
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**
(Intercept)	0.01596 (0.00000)	0.00856 (0.00000)	0.00865 (0.00000)	0.00866 (0.00000)
Coordination (p-value)	1.33009*** (0.00100)	1.32438*** (0.00100)	1.32391*** (0.00100)	1.32366*** (0.00100)
Funding (p-value)	-0.00588*** (0.00100)	-0.00611*** (0.00100)	-0.00606*** (0.00100)	-0.00508*** (0.00100)
Collaboration Degree Centrality (DCCOLL) (p-value)		0.00018*** (0.00100)	0.00017*** (0.00100)	0.00017*** (0.00100)
Coordination Degree Centrality (DCCOOR) (p-value)			0.00006 (0.17483)	0.00006 (0.13786)
Funding Degree Centrality (DCFUND) (p-value)				0.00000 (0.29471)
R^2 (Adj)	0.22644 (0.22644)	0.23095 (0.23095)	0.23097 (0.23097)	0.23097 (0.23097)
Observations (actors)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1

The statistical analysis was performed with UCInet (Borgatti et al, 2002)

Table h1: Evolution of Trentino ICT knowledge network number of nodes through time (2000-2014)

	Cumulative nodes	Difference of cumulative nodes	Active project nodes	Difference of active project nodes
2000	127	-	126	-
2001	161	34	143	17
2002	165	4	147	4
2003	197	32	172	25
2004	401	204	339	167
2005	528	127	460	121
2006	686	158	619	159
2007	774	88	649	30
2008	972	198	823	174
2009	1090	118	851	28
2010	1403	313	1037	186
2011	1610	207	1149	112
2012	1895	285	1256	107
2013	2158	263	1416	160
2014	2308	150	1391	-25
2015	2394	86	1100	-291

Table h2: Evolution of the collaboration ties in Trentino ICT knowledge network through time (2000-2014)

	Cumulative ties	Difference of cumulative ties	Active project ties	Difference of active project ties
2000	2863		2839	
2001	3113	250	2910	71
2002	3124	11	2919	9
2003	3404	280	3128	209
2004	9144	5740	6537	3409
2005	12409	3265	9520	2983
2006	16920	4511	13353	3833
2007	18086	1166	13776	423
2008	20999	2913	15729	1953
2009	20363	-636	12851	-2878
2010	28264	7901	17729	4878
2011	32082	3818	19399	1670
2012	37327	5245	20322	923
2013	41875	4548	23168	2846
2014	44835	2960	22742	-426
2015	46130	1295	15101	-7641

Table h3: Evolution of the coordination ties in Trentino ICT knowledge network through time (2000-2014)

	Cumulative ties	Difference of cumulative ties	Active project ties	Difference of active project ties
2000	131		129	
2001	170	39	152	23
2002	176	6	159	7
2003	218	42	191	32
2004	512	294	399	208
2005	686	174	547	148
2006	987	301	822	275
2007	1124	137	880	58
2008	1542	418	1211	331
2009	1771	229	1254	43
2010	2417	646	1595	341
2011	2838	421	1757	162
2012	3446	608	1919	162
2013	3997	551	2176	257
2014	4375	378	2095	-81
2015	4547	172	1532	-563

Table h4: Evolution of the funding ties in Trentino ICT knowledge network through time (2000-2014)

	Cumulative ties	Difference of cumulative ties	Active project ties	Difference of active project ties
2000	138		135	
2001	183	45	161	26
2002	193	10	171	10
2003	241	48	199	28
2004	540	299	420	221
2005	727	187	577	157
2006	1046	319	868	291
2007	1198	152	931	63
2008	1661	463	1298	367
2009	1948	287	1392	94
2010	2654	706	1773	381
2011	3143	489	1963	190
2012	3788	645	2121	158
2013	4398	610	2407	286
2014	4824	426	2289	-118
2015	5029	205	1670	-619

Table i1: Partition of actors of Trentino ICT knowledge networks according to their location for the last fifteen years (2000-2014)

	International Cumulative	International Active	National Cumulative	National Active	Local Cumulative	Local Active
2000	104	103	17	17	6	6
2001	127	110	23	22	11	11
2002	129	112	24	23	12	12
2003	154	132	27	24	16	16
2004	334	281	45	36	22	22
2005	450	392	50	40	28	28
2006	573	518	73	65	40	36
2007	616	511	97	81	61	57
2008	769	645	131	111	72	67
2009	832	625	163	137	95	89
2010	1081	796	217	168	105	83
2011	1241	879	246	191	123	89
2012	1482	980	278	193	135	83
2013	1691	1112	319	210	148	94
2014	1815	1119	339	187	154	85
2015	1871	905	366	147	157	48

Table i2: Participation of actors of Trentino ICT knowledge networks according to their location for the last fifteen years (2000-2014) in percentages (%)

	International Cumulative	International Active	National Cumulative	National Active	Local Cumulative	Local Active
2000	81,89	81,75	13,39	13,49	4,72	4,76
2001	78,88	76,92	14,29	15,38	6,83	7,69
2002	78,18	76,19	14,55	15,65	7,27	8,16
2003	78,17	76,74	13,71	13,95	8,12	9,3
2004	83,29	82,89	11,22	10,62	5,49	6,49
2005	85,23	85,22	9,47	8,7	5,3	6,09
2006	83,53	83,68	10,64	10,5	5,83	5,82
2007	79,59	78,74	12,53	12,48	7,88	8,78
2008	79,12	78,37	13,48	13,49	7,41	8,14
2009	76,33	73,44	14,95	16,1	8,72	10,46
2010	77,05	76,76	15,47	16,2	7,48	7,04
2011	77,08	76,5	15,28	15,75	7,64	7,75
2012	78,21	78,03	14,67	15,37	7,12	6,61
2013	78,36	78,53	14,78	14,83	6,86	6,64
2014	78,64	80,45	14,69	13,44	6,67	6,11
2015	78,15	82,27	15,29	13,36	6,56	4,36

Table i3: Partition of actors of Trentino ICT knowledge networks according to their organizational kind for the last fifteen years (2000-2014)

	Universities Cumulative	Universities Active	Research Centers Cumulative	Research Centers Active	Large firms Cumulative	Large firms Active	SMEs Cumulative	SMEs Active	Public Agencies Cumulative	Public Agencies Active	Other Institutions Cumulative	Other Institutions Active
2000	60	60	27	26	20	20	16	16	3	3	1	1
2001	65	64	36	31	32	22	20	19	7	7	1	0
2002	68	67	37	32	32	22	20	19	7	7	1	0
2003	77	76	44	38	35	21	28	25	10	10	3	2
2004	144	115	113	100	61	46	57	53	18	18	8	7
2005	186	159	149	132	75	59	84	77	21	21	13	12
2006	219	198	187	171	113	97	122	113	26	24	19	16
2007	227	195	203	178	134	111	154	119	35	30	21	16
2008	271	232	238	208	192	166	200	161	44	36	27	20
2009	287	237	258	208	205	155	236	166	68	58	36	27
2010	366	279	357	270	261	202	298	197	83	60	48	29
2011	385	291	388	281	316	237	359	235	96	65	66	40
2012	425	311	442	299	372	246	452	281	128	74	76	45
2013	449	318	500	332	425	278	543	345	148	84	93	58
2014	472	321	541	331	454	266	577	326	161	87	103	60
2015	481	263	555	256	468	214	601	260	174	69	115	38

Table i4: Participation of actors of Trentino ICT knowledge networks according to their organizational kind for the last fifteen years (2000-2014) in percentages (%)

	Universities Cumulative	Universities Active	Research Centers Cumulative	Research Centers Active	Large firms Cumulative	Large firms Active	SMEs Cumulative	SMEs Active	Public Agencies Cumulative	Public Agencies Active	Other Institutions Cumulative	Other Institutions Active
2000	47,24	47,62	21,26	20,63	15,75	15,87	12,6	12,7	2,36	2,38	0,79	0,79
2001	40,37	44,76	22,36	21,68	19,88	15,38	12,42	13,29	4,35	4,9	0,62	0
2002	41,21	45,58	22,42	21,77	19,39	14,97	12,12	12,93	4,24	4,76	0,61	0
2003	39,09	44,19	22,34	22,09	17,77	12,21	14,21	14,53	5,08	5,81	1,52	1,16
2004	35,91	33,92	28,18	29,5	15,21	13,57	14,21	15,63	4,49	5,31	2	2,06
2005	35,23	34,57	28,22	28,7	14,2	12,83	15,91	16,74	3,98	4,57	2,46	2,61
2006	31,92	31,99	27,26	27,63	16,27	15,67	17,78	18,26	3,79	3,88	2,77	2,58
2007	29,33	30,05	26,23	27,43	17,31	17,1	19,9	18,34	4,52	4,62	2,71	2,47
2008	27,88	28,19	24,49	25,27	19,75	20,17	20,58	19,56	4,53	4,37	2,78	2,43
2009	26,33	27,85	23,67	24,44	18,81	18,21	21,65	19,51	6,24	6,82	3,3	3,17
2010	26,09	26,9	24,73	26,04	18,6	19,48	21,24	19	5,92	5,79	3,42	2,8
2011	23,91	25,33	24,1	24,46	19,63	20,63	22,3	20,45	5,96	5,66	4,1	3,48
2012	22,43	24,76	23,32	23,81	19,63	19,59	23,85	22,37	6,75	5,89	4,01	3,58
2013	20,81	22,46	23,17	23,45	19,69	19,63	25,16	24,44	6,86	5,93	4,31	4,1
2014	20,45	23,08	23,44	23,8	19,67	19,12	25	23,44	6,98	6,25	4,46	4,31
2015	20,09	23,91	23,18	23,27	19,55	19,45	25,1	23,64	7,27	6,27	4,8	3,45

Figure 31a: Trentino ICT collaboration network for the period before the burst of economic crisis (2000-2007)

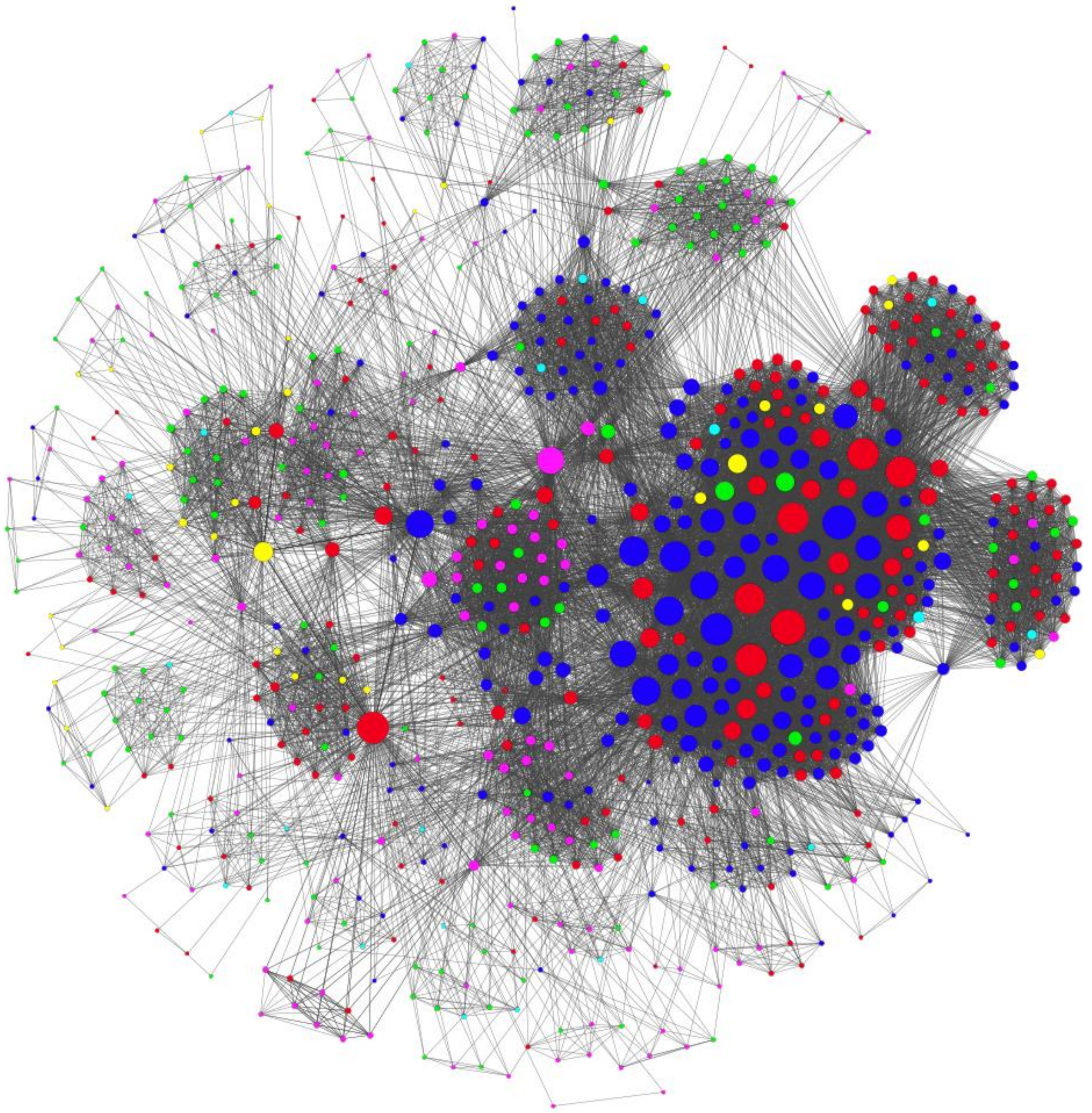

Figure 31b: Trentino ICT coordination network for the period before the burst of economic crisis (2000-2007)

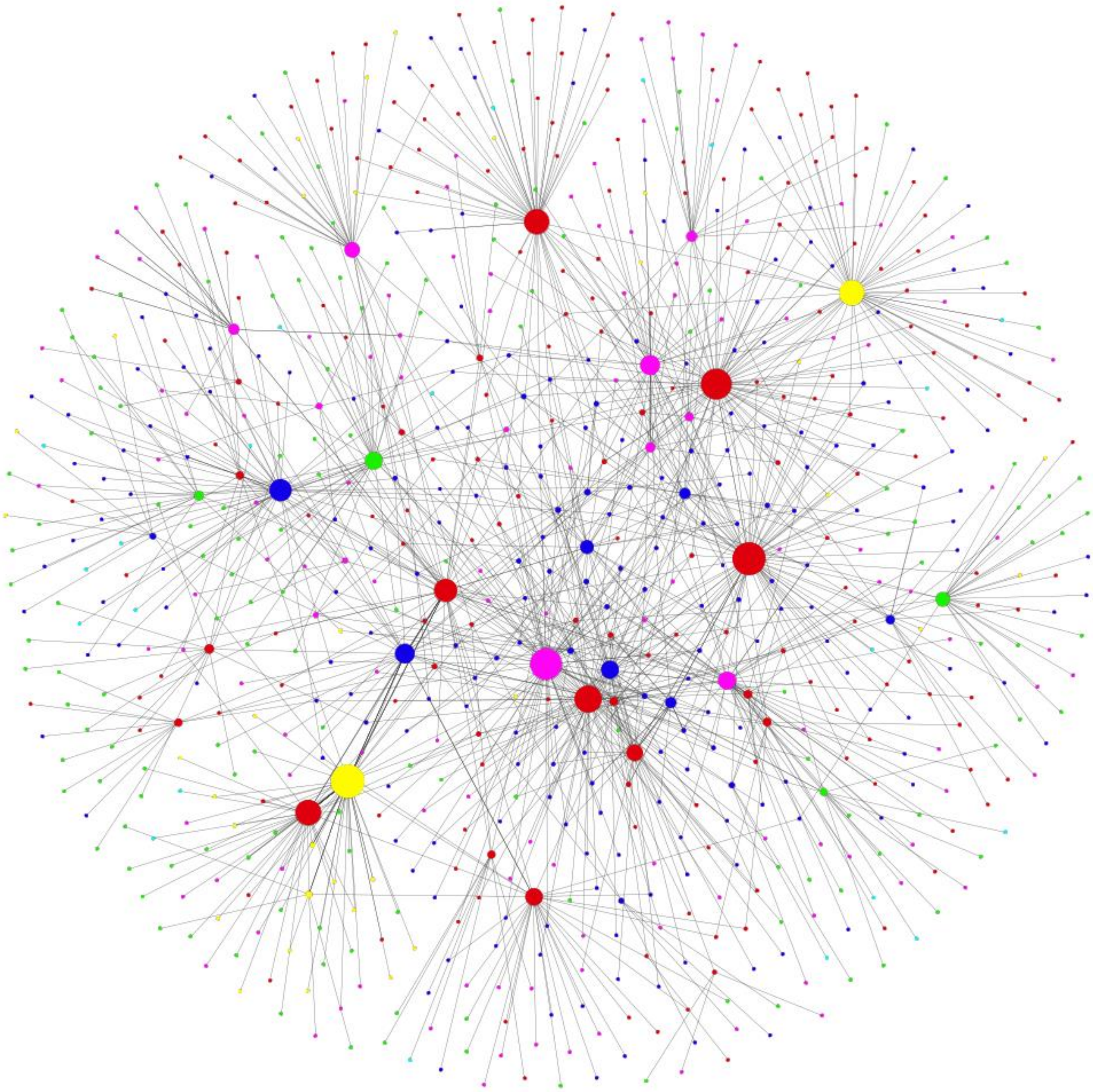

Figure 31c: Trentino ICT funding network for the period before the burst of economic crisis (2000-2007)

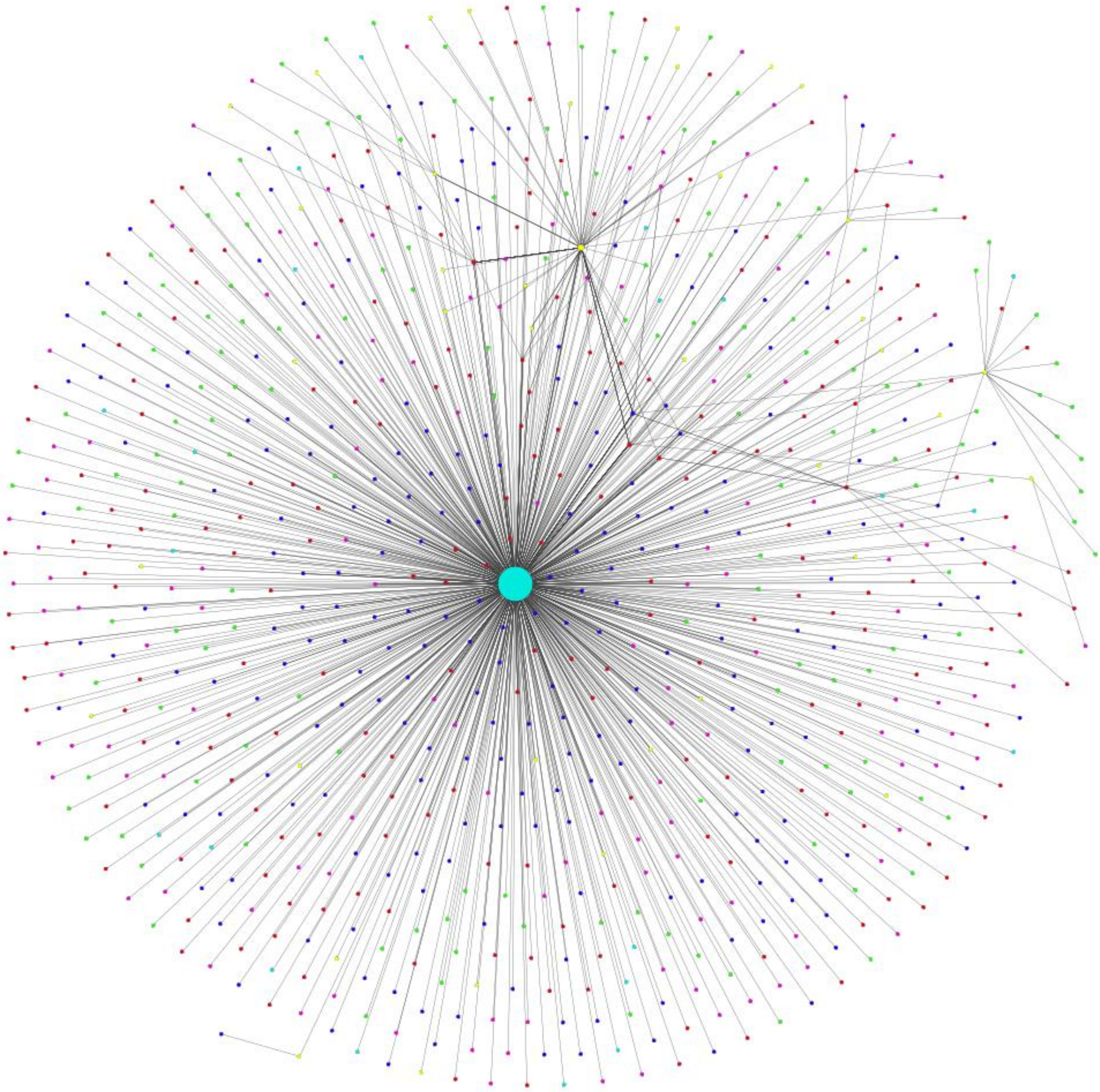

Figure 32a: Trentino ICT collaboration network for the period after the burst of economic crisis (2000-2007)

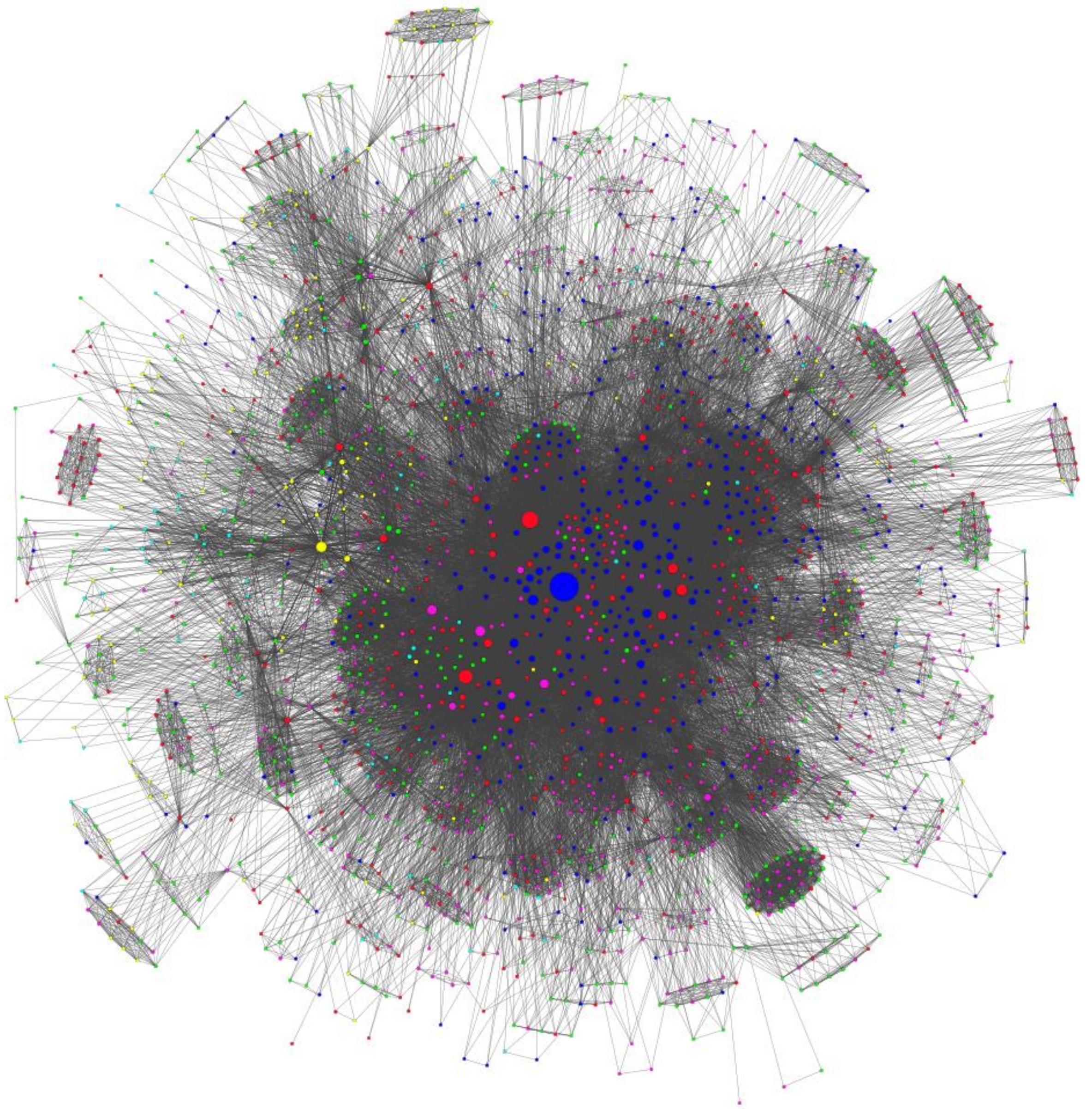

Figure 32b: Trentino ICT coordination network for the period after the burst of economic crisis (2000-2007)

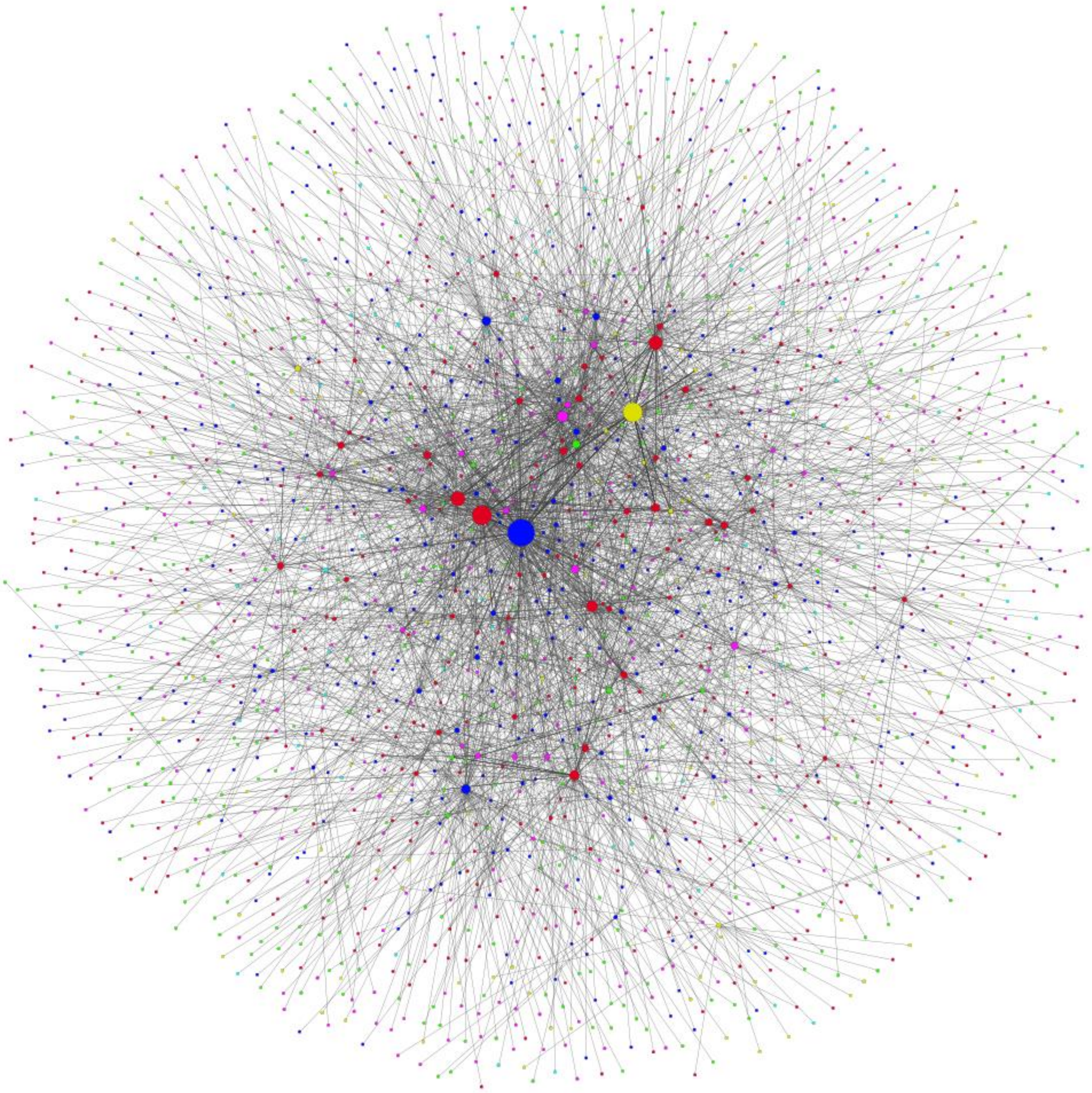

Figure 32c: Trentino ICT funding network for the period after the burst of economic crisis (2000-2007)

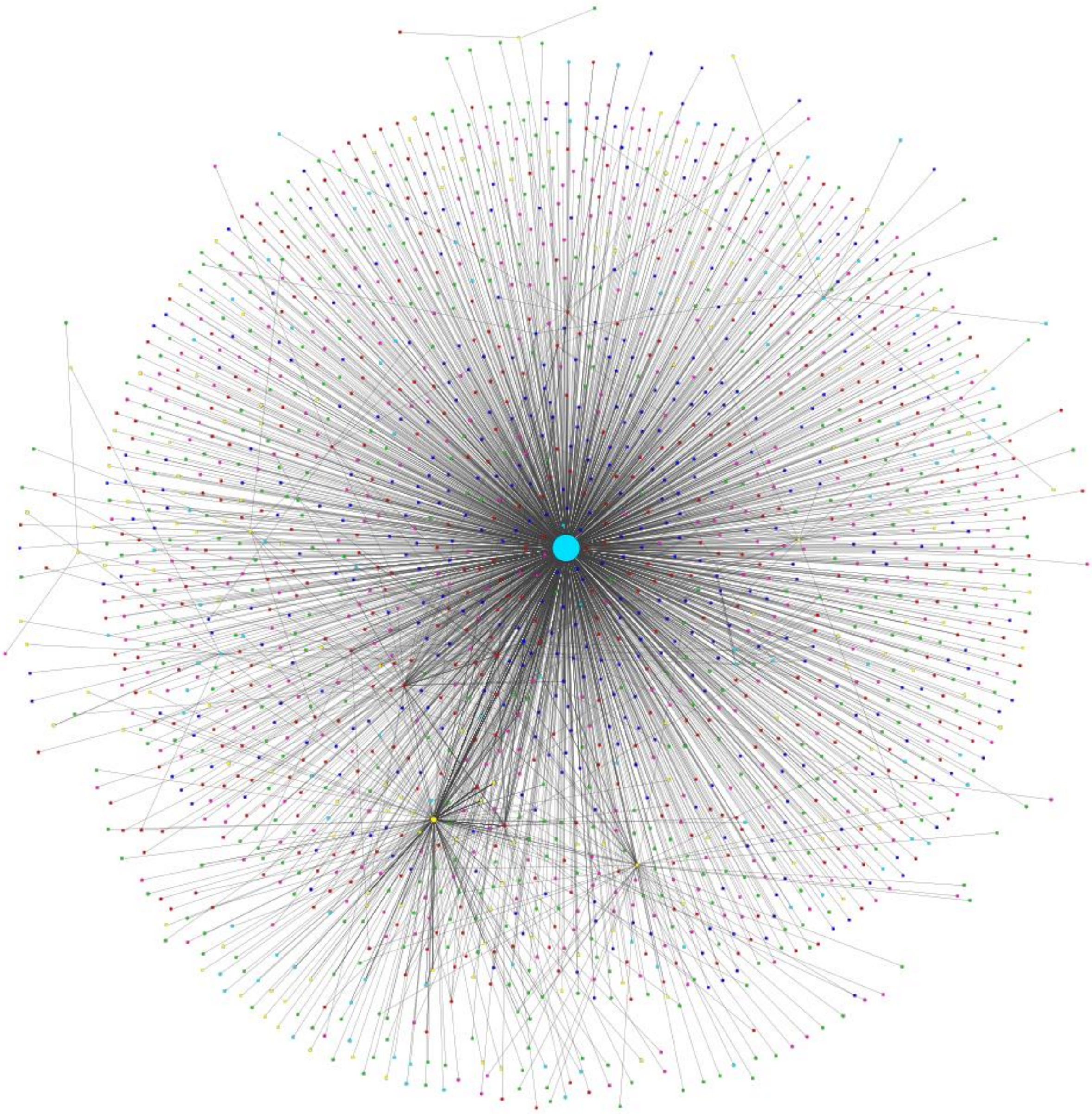

Table j1: Robustness check of the effect of the trust created by previous co-operations and proximity during low uncertainty periods (2000-2007) on the strength of the collaborations during high uncertainty periods (2008-2014)

Dependent Variable: Collaboration Network (2008-2014)				
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**
Intercept (p-value)	0.00536 (0.000)	0.00521 (0.000)	0.00515 (0.000)	0.00430 (0.000)
Collaboration 2000-2007 (p-value)	0.12126*** (0.00100)	0.12062*** (0.00100)	0.12065*** (0.00100)	0.11991*** (0.00100)
Coordination 2000-2007 (p-value)	0.53399*** (0.00100)	0.53225*** (0.00100)	0.53222*** (0.00100)	0.53251*** (0.00100)
Funding 2000-2007 (p-value)	0.14210*** (0.00100)	0.14172*** (0.00300)	0.14173*** (0.00100)	0.14205*** (0.00100)
Geographical Proximity (p-value)	-	0.03563*** (0.00100)	0.03312*** (0.00100)	0.03290*** (0.00100)
Institutional Proximity (p-value)	-	-	0.00257** (0.01798)	0.00250** (0.02997)
Organizational Proximity (p-value)	-	-	-	0.00422*** (0.00100)
R^2 (Adj)	0.02603 (0.02602)	0.02676 (0.02676)	0.02678 (0.02678)	0.02717 (0.02717)
Observations (Cases)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)	5,728,842 (2,394)
***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1				
The statistical analysis was performed with UCInet (Borgatti et al, 2002)				

Table j2: Robustness Check for the effect of early cooperation and proximity (2000-2003) on late collaboration network (2004-2007) in low risk periods

Dependent Variable: Collaboration Network 2004 - 2007				
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**
Intercept	0.02204 (0.00000)	0.02142 (0.00000)	0.02162 (0.00000)	0.01737 (0.00000)
Collaboration Network 2000-2003 (p-value)	0.13008*** (0.00100)	0.13006*** (0.00100)	0.13001*** (0.00100)	0.12422*** (0.00100)
Coordination Network 2000-2003 (p-value)	0.17670*** (0.00100)	0.17100*** (0.00100)	0.17126*** (0.00100)	0.17510*** (0.00100)
Funding Network 2000-2003 (p-value)	0.14983*** (0.00100)	0.14590*** (0.00100)	0.14589*** (0.00100)	0.14811*** (0.00100)
Geographical Proximity (p-value)		0.09999*** (0.00100)	0.11099*** (0.00100)	0.11001*** (0.00100)
Institutional Proximity (p-value)			-0.01120*** (0.00200)	-0.01083*** (0.00400)
Organizational Proximity (p-value)				0.01956*** (0.00100)
R^2 (Adj)	0.00572 (0.00572)	0.00823 (0.00823)	0.00832 (0.00832)	0.01095 (0.01095)
Observations	642,402	642,402	642,402	642,402

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1
The statistical analysis was performed with UCInet (Borgatti et al, 2002)

Table j3: Robustness Check for the effect of early cooperation and proximity (2008-2010) on late collaboration network (2011-2014) in high risk periods

Dependent Variable: Collaboration Network 2011 - 2014				
	Coefficients (no controls)	**Coefficients (1 control)**	**Coefficients (2 controls)**	**Coefficients (3 controls)**
Intercept	0.00492 (0.00000)	0.00478 (0.00000)	0.00474 (0.00000)	0.00398 (0.00000)
Collaboration Network 2008-2010 (p-value)	0.09508*** (0.00100)	0.09466*** (0.00100)	0.09465*** (0.00100)	0.09414*** (0.00100)
Coordination Network 2008-2010 (p-value)	0.18803*** (0.00100)	0.18614*** (0.00100)	0.18615*** (0.00100)	0.18634*** (0.00100)
Funding Network 2008-2010 (p-value)	0.03215*** (0.00200)	0.03181*** (0.00400)	0.03181*** (0.00200)	0.03200*** (0.00200)
Geographical Proximity (p-value)		0.02868*** (0.00100)	0.02724*** (0.00100)	0.02703*** (0.00100)
Institutional Proximity (p-value)			0.00147* (0.06194)	0.00142* (0.08492)
Organizational Proximity (p-value)				0.00382*** (0.00100)
R^2 (Adj)	0.01253 (0.01253)	0.01320 (0.01320)	0.01320 (0.01320)	0.01359 (0.01359)
Observations	3,859,260	3,859,260	3,859,260	3,859,260

***Significance-levels according to QAP: ≤0.01, **Significance-levels according to QAP:≤0.05, *Significance-levels according to QAP:≤0.1
The statistical analysis was performed with UCInet (Borgatti et al, 2002)