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Gravitating Towards the Quadruple Helix: International Connections for the Enhancement of a Regional Innovation System in Northeast Italy

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Abstract

The majority of previous Regional Innovation System (RIS) studies generally provide a rather static overview of the roles of innovation-creating actors. This article explores a single RIS in Trentino in Italy. The case shows that the roles of three actors (i.e. the provincial government, academia/research centers, and firms) are vital in creating the RIS, and that the provincial-level government policy is important in supporting the innovation activities of regional research institutions and firms aimed at developing their international connections. The public-private research collaboration and international connections of these actors are the key determinants of the development of an advanced RIS, but have largely been ignored in the extant RIS literature. This article extends the existing RIS and Triple Helix research to an international dimension, highlighting the complementary role of international connections within the RIS, thus reflecting a shift towards Quadruple Helix.

Keywords: regional innovation system; Quadruple Helix; international connections; Trentino

1. Introduction

Who are the innovation actors in a regional innovation system (RIS)? The literature on RISs has emphasized the key role of local knowledge intermediaries as regional knowledge

spillover agents (Audretsch and Keilbach, 2007; Fritsch and Schwirten, 1999). Extant research investigating RISs has focused on the regional-level dynamics, taking a Triple Helix approach. This stream of research illuminates the important role of three key actors, regional government, academia/research institutions, and firms, in streamlining RISs (Etzkowitz and Leydesdorff, 2000; Etzkowitz and Klofsten, 2005; Ranga and Etzkowitz, 2013). Studies applying the Triple Helix approach to RISs mainly focus on the regional-level analysis, and have under-emphasized the role of international relations as an additional dimension that can strengthen RISs (Leydesdorff, 2012; McAdam et al., 2012).

Recently, scholars have emphasized the need to understand the interactions and synergies between, not only the three sub-dynamics at the regional level, but also other potential dynamic interactions that can lead to the emergence of a RIS (Carayannis and Campbell, 2009; McAdam et al., 2012; Fitjar and Huber, 2015). In this vein, Leydesdorff (2012: 26) asks, "under what circumstances can increased interactions be expected to lead to synergies?" These scholars have emphasized the need to include additional dimensions, such as the role of civil society and stakeholders, in the Triple Helix – calling it the Quadruple Helix or an N-Tuple – in order to comprehend regional development and the knowledge-based economy (Carayannis and Campbell, 2009; Leydesorff, 2012; McAdam et al., 2012; Miller et al., 2016). To understand how and why one region has developed a stronger RIS than others, it is worth examining one particular RIS by including further aspects in the existing Triple Helix model. Hence, this article explores the role of international connections in a well-functioning RIS to investigate whether the RIS actors' international connections serve to support the RIS. In so doing, it is possible to identify factors that contribute to successful RIS development beyond the TH.

An RIS is a miniaturized national innovation system (Cooke et al., 1997). "The idea of an NIS and RIS relies on a notion of locally interdependent capabilities that are geographically bound" (Cantwell, 2014: 3). Nevertheless, the importance of international orientation and the relationships between regional actors is further elevated due to globalization, as international-national and even international-regional dimensions are more relevant for understanding the RIS of a particular region (Wagner, 2008; Leydesdorff, 2012). An RIS benefits from connections with foreign research and academic institutions and multinational corporations by diffusing their advanced knowledge throughout the region (Beugelsdijk et al., 2010; McCann and Mudambi, 2005). However, we know little about the functional role of international connections in the development of an RIS. To the best of our

knowledge, with very few exceptions (e.g., Leydesorff, 2012; Morrison et al., 2013), very limited empirical RIS research has investigated the n-helix from an international angle.

For our empirical context, we use the Province of Trento (Trentino hereafter) in Northern Italy. Trentino is a valuable research context as the small mountainous province has recently developed a strong regional research capability and innovation systems[1] (European Communion, 2015). This article aims to understand the salient characteristics of actors within the RIS of Trentino, and also the dynamic interactions among these actors from the international aspect. In order to do this, it applies the well-founded existing Triple Helix to illustrate the case of Trentino, and investigates the following question: what are the roles of key actors within the RIS of Trentino, and how does the RIS benefit from international connections?

In brief, by including international connections as an additional dimension, this article explains the dynamic functioning of the RIS in Trentino and the evolving nature of the TH. Further, it answers the recent calls of Leydesdorff (2012) and McAdam et al. (2012), suggesting that we should extend existing Triple Helix models step by step to gain more explanatory power (Carayannis and Campbell, 2009). The contributions of the current research are two-fold. First, it extends the existing Triple Helix by including international connections as an additional dimension, thereby gravitating towards the Quadruple Helix. This approach enriches the RIS literature by highlighting the RIS actors' international behaviors when engaging in the innovation process, thereby including international connections as a complement to the existing Triple Helix of an RIS. Second, this study introduces the successful RIS case of Trentino, which provides a useful benchmarking reference for regional government policy makers who wish to build sustainable RISs and encourage economic development.

[1] There are studies explaining innovation systems in the northeast Italian regions, including Veneto, Friuli-Venezia-Giulia, and Trentino-Alto Adige as a whole (e.g., Mancinelli and Mazzanti, 2009). However, very little work has been undertaken in analyzing the Trentino region, which has developed an enviable RIS compared to its larger neighbors.

2. Conceptual background

2.1. RIS and n-helix

An increasing number of innovation studies are examining the RIS topic, illuminating the roles of the key actors and their interactions within a region that contribute to regional innovation (see, e.g., Carayannis and Campbell, 2009; Danell and Persson, 2003; Fitjar and Huber, 2015; McAdam et al., 2015). Different innovation-creating actors play their roles within a region, with some of the knowledge produced by internal sources, but other knowledge infused with external sources. The latter sources include, not only those actors that directly cooperate with regional firms, but also other regional institutions such as research centers and universities, technology brokers, financial institutions supporting innovation, government entities, and individual workers in the labor market (Cooke et al., 1997). Among these, RIS research notes some common elements, including knowledge- and innovation-creating actors and intermediaries, and their interactions, among others (e.g., Cooke, 2008; Benneworth et al., 2009).

Knowledge is the most important element in the RIS as it contributes to the creation of innovation. Innovation is something that regions can be proud of because it increases their prestige (Rip, 2002). As such, the regions with the freedom to do so tend to valorize universities and research centers that produce new knowledge, thus feeding into the RIS. Related to this, Huggins et al. (2008) assert that universities and research centers serve as critical institutions in shaping and transferring innovation in a region. Extant studies also show universities to be one of the main sources of knowledge production, as universities and research centers produce scientific and technological knowledge, and train and educate graduates, which ultimately contributes to the innovation of regional firms (McAdam et al., 2012; Miller et al., 2014).

One important actor in promoting an RIS is the provincial/regional government (Etzkowitz and Leydesdorff, 2000; Rip, 2002). The national government provides the directives and the main rules and regulations, while the local regional government is in charge of taking smaller, more specific decisions. The power of regions differs from region to region. Some countries, such as France, grant regional governments very limited powers. Italy, which is mostly very centralized, does have some regions with a ‘Special Statute’ that are allowed to take more autonomous decisions, one example being Trentino. Other countries, such as the United States, Germany, and Switzerland, have the competences of the

national government narrowly defined, and national subdivisions (e.g. states, Länder, and cantons) are granted relative freedom in making decisions on regional policy.

The cooperation between regional and external firms facilitates innovation, in that the continuous exchange of knowledge, and spillovers between them, lead to knowledge being accumulated in the region (Fritsch and Schwirten, 1999; Lew and Liu, 2016). Thus, it is of crucial importance that innovation actors develop the absorptive capacity to obtain knowledge from advanced knowledge sources (Castellacci and Natera, 2013). As such, an RIS benefits from the interaction among local firms as well as external ones. A functional RIS mirrors a well-integrated value chain and also delivers better economic and innovation outcomes than does a short-term arm's-length relationship. Those firms that closely interact with regional, national, and international firms and institutions benefit from gained skills and know-how, which facilitates regional innovation.

Extant Triple Helix scholars argue for the importance of three main institutions and their roles in an RIS: (1) government, directing the rules of the game, (2) universities, creating and infusing knowledge into the system, and (3) firms, obtaining this knowledge and commercializing it (Etzkowitz and Leydesdorff, 2000; Etzkowitz and Klofsten, 2005; Leydesdorff, 2000; Lundberg, 2013). Early Triple Helix models emphasized the statist role of a regional government that would develop an institutional framework such as regulations and policies, thus directing the activities of the other actors in an RIS (Etzkowitz and Leydesdorff, 2000; Danell and Persson, 2003). In contrast, later work on the Triple Helix illustrates rather divergent roles for the three regional actors. That is, each of them is related and cooperates with the others, but informational and cultural barriers hinder collaboration (Siegel et al., 2003). Given this, one way of developing an RIS is to reduce regional dependence on the central government while adopting a more laissez-faire attitude at the regional level (Etzkowitz and Leydesdorff, 2000). Thus, the development of boundary-spanning skills by the actors helps to facilitate knowledge transfer among them within an RIS (Siegel et al., 2003; Lundberg, 2013).

Another stream of Triple Helix studies views the three actors as having overlapping functional roles in an RIS. This indicates that their roles are interrelated, confirming the importance of mutual collaborations and interactions among them. This approach provides a flexible framework for the analysis of RISs. This view highlights that, through the mutual cooperation among these actors, the outcomes of a particular RIS are maximized (Etzkowitz

and Leydesdorff, 2000; Etzkowitz and Klofsten, 2005). More recently, Triple Helix research has begun to focus on the dynamic interactions among the actors (Leydesorff, 2012; McAdam et al., 2012). For instance, Etzkowitz and Klofsten (2005) argue that the Triple Helix exemplifies a shift towards a knowledge-based society and is one of the key factors for regional development.

Overall, the existing Triple Helix approach provides a solid ground for explaining the dynamic of the RIS. Cultural and environmental changes may affect the stability of the system and the applicability of the model (Siegel et al., 2003). However, the Triple Helix can take various forms depending on the context examined (Etzkowitz and Klofsten, 2005). The most important implication of the Triple Helix approach for the RIS is evolutionary (Iammarino, 2005; Leydesdorff, 2000), in that a single actor's activities influence other actors' behaviors in the RIS, thus "the construction of careful balances between differentiation and integration among the three functions" determines the innovative environments for a region (Leydesdorff, 2000: 1441).

2.2. International connections of RISs: A shift towards Quadruple Helix

Economic geographers have recently highlighted the important role of international linkages for clusters (Bathelt et al., 2004; Hudson, 2005; Coe et al., 2008). This line of studies has suggested that international relations are important for the development and growth of regional clusters. Its key arguments are that a region achieves a high level of economic and technological outcomes by absorbing advanced technological knowledge and capital from across the global knowledge pool (Khan et al., 2015; Martin and Sunley, 2006). Similarly, scholars have suggested that global pipelines are important for regional firms to maximize the effectiveness with which they move resources across geographical space, by developing a common purpose at the regional and international level (Bathelt et al., 2004). A particular RIS can be connected to international research centers, universities, foreign partners and subsidiaries of multinational firms, for instance. In so doing, arguably, the behaviors of innovation-creating actors in the region can be richly buttressed from a much wider aspect. The importance of international connections is more pronounced for smaller regions due to the limited innovation-generating knowledge within such regions; therefore, the need to source international knowledge for innovation is vital (Morrison et al., 2013; Rodríguez-Pose and Fitjar, 2013).

On the one hand, from an inbound perspective, subsidiaries and R&D centers[2] of multinationals, or joint ventures between local and foreign firms, act as important gatekeepers for the flow of valuable resources for technological innovation into a nation and a region and back to the headquarters (McCann and Mudambi, 2005; Beugelsdijk et al., 2010; Khan et al., 2015). Further, an RIS can be strategically linked to outside lead regions such as knowledge hot spots (Bathelt et al., 2004) or centers of excellence (Cantwell and Janne, 1999).

On the other hand, from an outbound perspective, the regional actors can seek resources, efficiency, knowledge, and markets through internationalization (Dunning, 2001; Rugman and Verbeke, 2001). However, there is little research on international connections and RIS themes. Thus, the exploration of these regional innovation-creating actors' international behaviors could provide a window of opportunity for the extension of RIS research at the international level.

The overall functioning of an RIS also depends on the way the local actors, as part of the RIS, take advantage of the international linkages (Bathelt et al., 2004; Bathelt and Turi, 2011). For example, Porter (1998: 78) notes, "the competitive advantages in a global economy lie increasingly in local things – knowledge, relationships, motivations – that distant rivals cannot match". Although much of the traditional literature has noted that an RIS consists of firms and local support institutions (Pike and Tomaney, 1999; Asheiem and Isaksen, 2002), regional firms can still develop a global competitive advantage on the basis of having access to localized assets and an understanding of industrial development in the region. In the era of globalization and an interconnected world economy, one of the promising RIS strategies for a region, particularly for the Triple Helix, is to develop strong relationships with foreign institutions and markets. However, with few exceptions, such as the Quadruple Helix that includes an international element in the innovation system (Bathelt and Turi, 2011; Leydesdorff, 2012), a majority of RIS studies ignore the international dimension (Leydesdorff, 2012; Lorenzen and Mudambi, 2013). In this article, we hold the view that international connections are an important part of both the knowledge infusion into an RIS and the exploitation of markets, and are thus an imperative for investigating the international angle and gaining a better understanding of the Quadruple Helix-based RIS.

[2] For instance, the Science for Life Laboratory (SciLifeLab) reports that the Swedish bio sector benefits greatly from the investment of multinational R&D centers such as Astra Zeneca (SciLifeLab, 2015). SciLifeLab is a Swedish national research institution that is a collaboration between the government and universities, focusing on molecular biosciences.

3. Research methods

3.1. Research context

The empirical context of this study is the Trentino region, where a sophisticated RIS already exists. Regional institutions, such as the publicly owned research centers and the University of Trento, and firms are active in the field of innovation (Trentino, 2014). Numerous public-private partnerships and collaborations have been established and promoted, and the region vaunts its high level of innovation. One of the reasons Trentino is one of the leading innovative regions in Italy is due to the existence of numerous projects encouraging innovation. The region owns a 'Special Statute' in Italy, which allows it to allocate monetary resources independently according to the provincial policy preferences and needs. Taking into consideration the small population of Trentino, it is interesting how many innovative activities are undertaken per capita (Eurostat, 2015b). The inhabitants in Trentino are around 0.53 million, as opposed to the almost 10 million in Lombardy. According to the Italian government's statistics agency (ISTAT, 2009), the number of persons employed in R&D in Trentino was, on average, 6.4 out of 1,000 inhabitants, versus the national average of 3.8 and the EU 27 average of 4.9. These figures show that there are a high number of innovative activities in the small region, making the Trentino context suitable for studying RISs.

3.2. Case study

Qualitative research is often seen as a second-best choice due to the limited level of external validity it offers (Gioia et al., 2013). Nevertheless, investigating a specific RIS with a case study approach can greatly help us to provide a holistic and deeper understanding of the RIS in a particular region. We took great methodological efforts when selecting the conceptual framework prior to data collection, developed a semi-structured questionnaire, and conducted in-depth interviews with key informants (Piekkari et al., 2010). The research framework applied in this study takes inspiration from the Triple Helix (Etzkowitz and Leydesdorff, 2000; Etzkowitz and Klofsten, 2005). This approach helps us to identify both external and internal actors within the RIS.

3.3. Data collection and analysis

We conducted semi-structured face-to-face interviews with senior managers and policy makers from provincial government, firms, and academic/research institutions in Trentino. We covered a range of topics in these interviews, including the role of the provincial government in innovation, provincial-level innovation policy, support for local firms, the role

of intermediary research organizations, R&D centers, the role of universities in the region, university-industry linkages and innovation performance, public and private collaborations for innovation, specific incentives for firms to attend international events, regional innovation in general, the relationship between the regional government, research institutions and firms, the regional innovation actors' engagement in international relationships, cooperation between research centers and firms in Trentino, how the government supports research and business activities, and issues related to the interaction mechanisms between innovation-creating actors. The overall goal was to probe, corroborate, and cross-check the interviewees' responses. The main questions related to the topic were asked of all interviewees; however, the questions were kept flexible to allow deeper investigation, especially when differences emerged on certain issues amongst respondents. In order to reduce bias, data were also collected via secondary sources, including research papers, articles published in newspapers, and central and local government policy documents. Overall, this approach has further improved the validity and reliability of the study.

All the interviewees had PhD qualifications and were knowledgeable about the RIS in Trentino. The interviews were conducted from March to August 2014. Each interview lasted for approximately 100-120 minutes. We also assured the interviewees that the information would be treated as confidential and only used for the purpose of the research. First, we interviewed the managers of two firms in the Province of Trento, and then the Head of the Department of Innovation, Research, and ICT of Trentino and the Director of the Provincial Agency Trentino. Later, they introduced us to senior managers in academic/research institutions. We conducted interviews with two representatives of academic and research institutions, namely the Head of the Scientific Research and Technological Transfer Division at the University of Trento and the Head of the Technological Unit of a regional research center. Table 1 summarizes the profiles of the six interviewees. In total, we conducted ten interviews with the most knowledgeable individuals from each Triple Helix of Trentino. The interviews were conducted in Italian and later translated into English with the assistance of professional bilingual interpreters.

Regarding data equivalence, we ensured functional and conceptual equivalence to improve the trustworthiness of the research in terms of credibility, dependability, conformability, and transferability (Sinkovics et al., 2008; Symon and Cassell, 2012). As for credibility, we interviewed highly qualified interviewers from the government, research institutions and firms. Next, the themes and findings identified in the early research stage were sent to some of the interviewees to obtain their comments on them, which ensured the

dependability of our findings. Regarding the credibility of the data collection, the case firms and institutions are from the Trentino region and the initial interviewees introduced other very reliable interviewees, ensuring conformability. In order to enhance the transferability of our study, the well-studied Triple Helix was chosen to examine the RIS of Trentino. In particular, we further looked at the international dimension of the n-helix. Lastly, we interpreted the findings utilizing the extant literature.

Insert Table 1

Regarding the analysis principle, following Gioia et al.'s (2013) suggestion, we took a two-stage approach. At the beginning, there were a number of different codes and various pieces of uncategorized text. Then, we labelled these categories and reduced the amount of data into a more manageable and neater form. In parallel with conventional content analysis, we conducted the summative content analysis by using keywords (e.g., collaboration, foreign/international, policy) during the data analysis process (Miles and Huberman, 1994; Hsieh and Shannon, 2005). This flexible analytical approach is useful when aiming to understand the meaning of a text and reclassify it into different subgroups according to that meaning. When classifying and organizing the data, we used the computer-assisted qualitative data analysis software Nvivo10. This technique helped us to organize the raw data into different topics, and to code and sort the data according to different themes. It should be noted that a computer cannot do this analysis by itself, but it is helpful for storing and structuring the material. Through this process, we developed the analysis template, consisting of three RIS actors in a column and activities in a row.

4. Findings

4.1. Provincial government support for innovation and internationalization

In Trentino, voluminous innovation outcomes from firms and research institutions are financially supported by the regional government. The Agenzia Provinciale per l'Incentivazione delle Attività Economiche (APIAE: the Provincial Agency for Incentivizing Economic Activity) is the regional government agency, directing the funds to economic actors within the province. The APIAE financially supports regional innovation activities, including industrial research projects, experimental development, research collaborations, and internationalization, among others (APIAE, 2015). One of our interviewees responsible for the Department of Knowledge for the Province of Trentino explained the advantages of the autonomous region:

> *"The Province of Trento is autonomous …* Since 2010, after the Milan Pact, the University of Trento has been completely financed by local and regional funding. So not only does the province finance the research from the research centers, but the university*'s* research is completely financed by the Province of Trento as well. The province has the absolute right to devolve funds where it wants, and expenditure is decided by working with researchers. For example, the university, if compared to the regional bureaucracy that runs it, has a very high degree of autonomy for something of its nature [i.e., *a publicly funded institution]."* [Government A]

In 2011 the province introduced Rule n. 6, supporting the R&D and the innovation of firms via incentives and contributions. One of the interviewees who was in charge of a regional research center explained the advantages of the funds:

> *"The regional funds for those projects, if* recognized and accepted by the region, range from a minimum of 40% to a maximum of 80%. The maximum of 80% can be reached only through cooperation with Fondazione Bruno Kessler (FBK) or another research center [...] *"* [Research center A]

Those funds are given to firms only if they fulfill certain requirements. For example, the CEO of one energy and environment cluster remarked:

> *"T*here are brackets stipulating that a small firm gets more than a medium and a medium firm gets more than a large firm. Industrial R&D is subsidized more than pre-competitive development *[…]"* [Firm A]

The regional government also supports the international networking of firms. For instance, it compensates firms for the cost of participating in international trade fairs or overseas commercial events. In addition, the regional government covers 25-70% of costs related to international marketing, consulting service fees, business analysis, human resources development, and the hiring of new graduates in Trentino. One of our interviewees said:

> *"[…]* with incentives and contributions that help to cover part of the internationalization costs of the firms. Those contributions help to diminish the costs of going to international trade shows, the costs of living and travel expenses when firms go abroad to open new relations with new clients and new markets, reducing costs by 40-*50%."* [Government B]

These findings indicate that the government is playing an important facilitative role and encouraging regional firms to develop international connections. Recent research suggests that open clusters are an important way for firms to gain knowledge and develop innovations (e.g., Maskell et al., 2006; Maskell, 2014). In addition, Trentino Sviluppo (the provincial government agency) helps regional firms to expand abroad. For instance, it offers

various services that aid regional firms' internationalization, including helping with the paperwork for regional firms' international businesses activities. This finding hints at the important role played by these intermediary organizations in supporting firms, and mostly SMEs, in developing international networks. This indicates the importance of intermediary agencies for regional innovation, together with the Triple Helix in RISs, shifting towards Quadruple Helix-led technical change and innovation (Carayannis and Campbell, 2009). Also, the regional government agency helps support local SMEs with attending international trade fairs in order to build relationships with potential foreign commercial and technological collaboration partners. The Director of the Innovation and Development Department of the government agency explained:

> *"T*here is the activity offered by Trentino Sviluppo [the provincial government agency], which last year was offered by the chamber of commerce thanks to Trentino Sprint. This activity is meant to accompany firms moving into international markets, via systems integration and integration projects concerning supply chains and markets.*"* [Government B]

The provincial government's international policy and intermediary organizations directly support the innovation and internationalization of the regional firms, and thus the advancement of the RIS of Trentino. These findings are in line with the views of Carayannis and Campbell (2012: 38), who aver that "the sustainable backing and reinforcing of knowledge and innovation in the glocal [global and local] knowledge economy and society requires a substantive supporting of the development and evolution of innovation cultures". Regional/local firms' international networking and the provincial support for their participation in international technological events and trade fairs facilitate regional innovation activities including technological R&D investment and market expansion (Filipescu et al., 2009). Firms in Trentino have been well equipped to conduct international business by drawing on regional innovations and government support.

Apart from the above findings from the interviews, R&D expenditure and intensity are key proxies for innovation. As shown in Table 2 and Figure 1, the level of R&D expenditure in Trentino is much higher than that in its neighboring regions and the Italian average (Eurostat, 2015a; PAT Statistics Survey, 2014). The public research institutions in Trentino have consistently increased their R&D investment. Further, the amount of public expenditure devoted to R&D (52% of the regional R&D) is larger than that in the rest of the country (42% of the national R&D). As presented in Table 3, Trentino invests a large part of

regional GDP in scientific research activities (i.e., R&D intensity) – its 2012 R&D expenditure as a percentage of regional GDP (2.34%) was the highest in Italy (Eurostat, 2015b).

Insert Tables 2 and 3 and Figure 1

4.2. International collaborations of research institutions

Our findings suggest that international connections and the regional research institutions have played a key role in the acquisition of knowledge and resultant innovations by the local firms in Trentino. One of our interviewees responsible for scientific research and transfer of technology at the University of Trento emphasized the importance of the internationalization and positioning of the university:

> *"I have no doubts that the* professors are integrated internationally speaking, because this presence is important, and they often have existing relations worldwide with many universities, such as in Australia, Iceland, New Zealand, Japan, and so on [...]*"* [University A]

To support the research projects undertaken by academic researchers, the Division of Scientific Research and Transfer of Technology was created in the 1990s. It has grown consistently over the years, demonstrating the university's decision to concentrate more resources on research. Our interviewee responsible for the Department of Knowledge Transfer in the province emphasized that research project collaborations are generally created through a bottom-up approach. This means that researchers find or develop interesting projects on their own. However, there are a few cases of a top-down approach having been taken, with the regional government deciding where to direct projects:

> *"*There is an important mixture, this important equilibrium between the suggestions that can be made by the political entities (in this case, the autonomous Province of Trento) and the contribution made by people on the ground, including research centers and international innovation centers.*"* [Government A]

Therefore, it can be assumed that there is a large role for public sector funding at an academic level as well as in the private sector; both firms and research centers cooperate with the government in the financing of projects. Researchers in Trentino at a university or research center level are involved in international projects with counterparts in the US and EU as well as other countries, with recent examples including researchers in Mozambique, Southern Australia, and others. Most importantly, to foster these relations, the projects chosen for subsidization are internationally oriented. A prime example is the case of Mozambique's

joint project in Information Computer Technology. These collaborations are not only a matter of operating in an activity together, but are important gateways to initiate new relationships with potential new commercial partners. Students from Mozambique were invited to come to Trento and after having learned some skills, went back and applied them to their local industries, while researchers from Trentino, who all collaborate in some capacity or others with local industries, gained valuable contacts in an untapped market.

Along with universities, there are two main research institutions, Fondazione Bruno Kessler (FBK) and the Edmund Mach Foundation, out of a total of twenty private and public research institutes in Trentino. In the innovation process, the research centers act as a vital bridge between the universities and local firms for commercializing scientific research outcomes and inventions. For instance, FBK allows the firms to make use of the research outputs they conduct through soliciting private-sector financing and helping researchers to join firms' projects. In this exchange scheme, researchers can be directly employed by the local firms, thus benefiting from knowledge exchange. They can use all the laboratory facilities and infrastructure at the disposal of the research center during their employment, giving firms easy access to scientific research activities and outcomes. This provides R&D resource-constrained local SMEs (e.g., constrained in terms of human capital and technological knowledge) with learning opportunities for upgrading their internal R&D capabilities and enhancing their absorptive capacity. Further, at the end of a research collaboration contract, firms can have the option of hiring the researcher on a full-time basis. This virtuous collaborative-innovation circle developed between the private and public sectors strengthens the RIS of Trentino. Further, in order to strengthen the relations between universities and industry, the University of Trento has developed internship programs, offering a variety of opportunities for students to experience real-world industry practices. Our interviewee at the University of Trento explained that the academia-industry tie in Trentino has been developing well: *"The University of Trento is certainly very active in this* area. Recently, some pacts with Confindustria [the Italian industrial association] have been *made, not only for internships but also for the cooperation of PhD students with firms"*.

The university is also internationally connected via research, mobility, and exchange programs. This is an important element that allows local scientists and researchers to work with regional firms on R&D and innovation. The Trentino region is well connected with other regions regarding the mobility of its graduates. According to Alma Laurea (a statistics research institute in Italy), around 15% of Trentino graduates move to another region within

the first three years of leaving university, while around 20% of the graduates of other regions find their first job in Trentino (University of Trento, 2014). The Piano Strategico (strategic plan) of the University of Trento aims to increase the global visibility of the university by increasing research activity, mobility, and exchange programs, supporting collaborations with firms, increasing the ratio of foreign students, and encouraging the careers of students abroad. One of the programs that is increasing the level of internationalization is the EUREGIO pact between the three universities of Trento, Bolzano, and Innsbruck in Austria. The purpose of this partnership is to produce research synergies. Examples include the opportunity for PhD students to work with professors from any of the three universities, and the fact that some professors will conduct research or hold lectures in more than one university, for students who have the possibility to work jointly towards a master's dissertation. Finally, there are other projects, as one of our interviewees mentioned:

> *"*For the last four years we have spent a sizable amount of money on projects co-funded by the EU, the Marie Curie projects, which work towards mobility for PhD students in the EU. We have funded about sixty to eighty scholarships over the course of three years. These have involved incoming students (coming to Trento for their PhDs), outgoing PhD students going to other EU universities, and integrative projects involving people from Trentino living abroad but willing to come back to Trentino to conduct research.*"* [Government A]

The university has gained competitiveness and occupies a higher position in the national and international rankings than previously. For instance, according to the Italian newspaper Corriere della Sera (2014), the University of Trento ranked as the best public university in Italy for teaching quality. Furthermore, the university is one of the few Italian universities ranked amongst the top 300 universities worldwide in the Times Higher Education 2014-15 rankings (University of Trento, 2015). The above findings indicate that the strong international connections of the regional academic and research institutions and the collaborative research between them explain the advancement and dynamic nature of the RIS of Trentino.

4.3. Local firms' international connections and R&D collaborations

Trentino has a strong agricultural base that includes apples and wineries, and the tourism sector is also well developed due to the alpine environment. However, the majority of regional firms are SMEs and family-owned, implying a deficiency of large innovative firms that could influence regional innovation activities (European Commission, 2015). The region's main industrial sectors include textiles, construction materials, machineries, and

food processing. The region has strategically developed diversified industries, not specializing in a particular industrial sector. One of our interviewees explained that the economic policy of the region was to encourage many diverse firms rather than focusing on creating a single industrial cluster:

> *"The* province has always tried not to focus its economy on a few sectors. And this has helped us, especially during the crisis, which has impacted some sectors. Just think of the textile sector in Tuscany. The once prosperous town of Prato, where this sector was centered, saw its economy collapse. When the furniture cluster collapsed in Friuli the situation was similar. Our economic policy was always diversified and not sectorial. But the disadvantage is that, when there is an economic boom, the *gains are smaller."* [Government A]

Despite the liability of smallness of the regional firms, Trentino has built up strong research collaboration practices. One example of an industry cluster in the region is the Technological District, an organization with shareholders in both the public and private sectors that operates like a public-private partnership, helping firms in the sustainable construction industry. The owner of a manufacturing company in the cluster explained that there are not many clusters in Trentino due to the small size of the region. However, there are small aggregated groups of regional firms, which form a relatively small consortium.

We interviewed the CEO of the Energy and Environment Cluster in Trentino which comprises over 300 firms. Even after the economic recession, unlike many Italian firms that were forced to close down, this firm was able to keep its size and remain stable, much like the rest of the firms in Trentino. The firm's revenue had increased by 10% in 2013 due to two factors: innovation and international orientation (Trentino Industriale, 2014), and he delivered a message about the importance of internationalization to the firm: *"We work 85% with* foreign countries directly, but if we consider the fact that our Italian clients are also exporters, we could say that we work almost entirely with foreign countries. 94-95% of our sales come from abroad". International orientation is not a panacea for the firm's success, but a high degree of internationalization is closely tied to innovation output. Related to this, one of our interviewees stated,

> *"We put a lot of emphasis on innovation, proven by the fact that 99% of our* products are less than five years old, and 70% of the products that have been on the market for more than one year have seen a modification of their production details in the last year. We put a lot of effort into the innovation both of products and processes, as well as into *our technological business cycle."* [Firm B]

The innovation of products also depends on the workers' know-how and innovative capabilities. Some capabilities related to the specific production machinery can only be developed in-house. The owner of Firm B mentioned that public-private partnership fosters a technological cluster in the field of sustainable building construction, renewable energy sources, and intelligent territorial management technologies. This suggests the emergence of smart specialization in Trentino, showing the contributions of R&D collaboration between the public and private sectors to innovation outcomes. The interviewee also stated that there are some internal skills and competencies that are closely tied to the firm, which cannot be acquired from the outside. However, there are other skills and know-how that can be transferred from foreign countries to the regional firm. For instance, Firm B operates its businesses in foreign countries such as in France and the UK, and offers consulting services in the construction of sustainable buildings in the branch of luxury construction. The majority of new product development derives from cooperation with foreign research centers and international research institutions. This indicates the importance of developing linkages, for the development of innovation at the regional-international level.

Regional firms' innovation is supported by the province's funds, which are provided only when the firms fulfill policy requirements guided by the regional government. For example, there are stringent requirements preventing firms from laying off workers within a specific time period if they are to receive funds from the province. For example, Firm A received some funds for cooperating with research centers when conducting what is termed collaborative research. Benefiting from the innovation of products and processes, the firm has a high-quality production process and is able to compete in the global marketplace.

In addition to the already illustrated success factors of the regional firms (i.e., internationalization, public-private research collaboration, and governmental support), the Director of the Innovation and Development Department of the government explained the dynamic nature of the RIS of Trentino:

> *"*[...] the quality of the products, the reliability of the products as a whole, and also financially speaking, and a great attention also towards sustainability and environmental issues *[...] I believe that for many years there has been a tradition* and a vocation towards innovation. The tradition starts also from the innovation centers: we have the research center called Mach, founded at the end of the 1800s, and FBK, which is focused on technology in a broad sense. On the other hand, Mach operates in the agriculture sector and focuses on technologies applied to

agriculture. FBK has existed for over fifty years. Therefore, there is great attention paid to innovation that is strongly related to *the products."* [Government B]

The above findings show that the recent n-helix research emphasizing the role of multiple stakeholders and a shift towards extended Quadruple Helix in regional development (McAdam et al., 2012; Miller et al., 2016). Importantly, the international connections of regional innovation actors complement the advancement of the RIS on the basis of strong government innovation policy initiatives and R&D collaboration in the region, leading to a strong RIS.

5. Discussion and conclusions

This article takes an extended approach by exploring the role of international connections in the enhancement of an RIS. Drawing on the Triple Helix as a base model, it examines the roles of the regional government, academic/research institutions, and firms, in the regional context of Trentino. This approach guides us towards an understanding of how these RIS actors' activities relate to each other and the wider international world. By doing so, the article identifies a dynamic RIS nature and a shift towards Quadruple Helix aspects for exploring dynamic regional-international connections for the co-creation of innovation in an RIS (see Table 4). The Trentino case demonstrates that international connections are an important part of an RIS, enabling the region to overcome territorial limitations and to increase its prestige and success, especially in the current globalized economic system. This could point the way towards the dynamic evolution of RISs into trans-regional and trans-national innovation systems.

The dynamic interactions among the regional government's policy and support, university/research institutions, and firms' innovative businesses, help explain the vibrant nature of the RIS of Trentino. In particular, our case highlights the contribution of international connections to the n-helix within the studied RIS, which sustains the development of the competitive RIS. It suggests that there are positive connections between the RIS and internationalization (Filipescu et al., 2009; Halilem et al., 2014). The role of the governmental innovation and internationalization policies for the local firms and academic/research institutions, in supporting regional innovation activities, are critically important. Thus, the findings suggest that well-structured regional innovation policies targeting economic, scientific and technological actors are imperatives for building these actors' capabilities and international networks. This will allow those actors to access and

acquire knowledge that will enable them to create better RISs (see Table 4). Despite its smallness in terms of geography and demography, and the deficiency of large local firms/clusters or multinationals, the region of Trentino has developed both strong internal research collaborations and capabilities, and an external network with foreign institutions. Thus, we infer that the provincial government's support for innovation promotes regional innovation actors' internationalization as well as the development of an RIS.

The aforementioned internationalization adds value to research organizations and helps academia to have an impact across the RIS. Local firms in Trentino have often demonstrated themselves to be fairly innovative and export-oriented. This case shows that cooperative innovation activities can be created via local or international research centers and universities. In addition, forms of cooperation exist with international clients, bringing firms closer to the needs of the international market. Such connections with foreign suppliers and clients permit the local firms to remain competitive and to gain from both upstream and downstream collaborations with their partners. The illustrated case is a single example. However, the case underlines the positive aspects of external relations. It is important to note that, even for firms operating exclusively locally, being connected to regional research centers permits them to indirectly access and acquire external knowledge from international sources.

Arguably, the international connections of the RIS actors are a very complementary part for forming an extended wider network of the RIS. This view is in line with Breschi and Lissoni (2001), in that technological spillovers are weaker in a 'closed' cluster. As shown in the Trentino case, international connections have been beneficial for the enhancement of the RIS. Thus, a regional 'open' environment connected with the outside world would seem to have more benefits than a closed cluster or region (Fitjar and Huber, 2015). The regional government of Trentino contributes towards supporting activities that create international RIS connections, such as helping local firms to attend international trade fairs and marketing events. These spaces have been noted to be important in helping participating firms to gain valuable knowledge and to build inter-organizational networks (e.g., Maskell et al., 2006; Maskell, 2014). The local government also helps academia to participate in international projects, which is entirely dependent upon the provincial funds. As such, the RIS of Trentino can be seen as an efficient provincial model of internationalization, and there exists a virtuous innovation cycle in the RIS: the autonomous regional government decides where and how to direct part of its monetary resources. This facilitates the innovation and knowledge creation

process in the region. Academia is also internationally oriented due to the public funds available to it, and collaborates with the regional firms. The firms cooperate with both regional and international firms to produce innovative products/services. Further, they participate in international trade fairs and events due to the strong governmental support helping them to build such connections. Through these processes, the small regional firms can access up-to-dated market knowledge and create more innovation outcomes and business opportunities (Fitjar and Rodríguez-Pose, 2013; Morrison et al., 2013), and their profits in turn compensate for the governmental policy support.

In order to increase the degree of internationalization of an RIS, it is important to create and embed the value of international connections among all actors in the region. In the interconnected globalization era, the existing Triple Helix approach to RISs can "be extended algorithmically, for example, with local–global as a fourth dimension" (Leydesdorff, 2012: 25). The international connections of the Quadruple Helix will positively affect the innovation landscape of a region, and increase the level of glocal knowledge sharing and transfer across the RIS, leading to a virtuous cycle in which innovation capabilities are built up in the region. As such, international connections can be closely related to innovation capabilities (Filipescu et al., 2009; Halilem et al., 2014). Overall, Table 4 presents our findings, illustrating the provincial government policy on internationalization and the international connections of academic/research institutions and regional firms, and how their dynamic interactions contribute to the RIS. The governmental policy provides fertile innovation and internationalization soils for the RIS which affect the behaviors of research institutions (nurturing knowledge) and firms (reaping innovation outcomes) to seek international connections in particular. These findings are in line with the notion of the bathtub analysis on social phenomena (e.g., Coleman, 1990) and institutional approach on innovation systems (e.g., Nelson, 1993), highlighting the importance of an institutional perspective on the dynamic Quadruple Helix. Our study provides reflections on how RIS-related transitions develop and how institutions and innovation actors' interactions in an RIS evolve from the international perspective as shown in Table 4. The international connections of regional academic/research institutions and firms, along with regional government support, can strengthen the development of an advanced RIS, and thus international connections complement the roles of the Triple Helix. As such, this research extends the existing Triple Helix approach to the Quadruple Helix in RIS research (Barbosa and Faria, 2011; Carayannis and Campbell, 2009; Cooke, 2011; Leydesdorff, 2012). The Trentino case provides important

insights into the unique regional characteristics of a successful example of regional innovation in a small area

Insert Table 4

5.1. Implications for policy makers and managers

One implication for regional governments is the importance of international linkages among all institutions within an RIS. This means that regional firms should be informed about the importance of engaging in a certain level of international business/research activities. A regional/local mentality limits the potential of good ideas regarding innovation. Innovation is crucial for the competitive advantage of a region, and it can draw advantages from international linkages. Financial resources alone cannot create a competitive RIS environment, but should be accompanied with a regional culture and mindset that is open to the international arena. Also, policy makers should be aware that increasing the interaction at a research/academic institution level, and providing RIS actors with a basic industrial culture, could help to embed into the society basic industrial knowledge and entrepreneurial skills, ultimately affecting in a positive way the innovation of the region. This study also has some managerial implications. Managers should attempt to have an open-minded approach, and should especially try to hear the advice offered by the local institutions and academia. This could also be improved by employing highly skilled laborers such as new graduates, who are able to offer fresh points of view and ways of approaching problems to the innovation process. Furthermore, managers should consider actively participating in international trade fairs and events to seek market opportunities and fresh ideas for the development of innovations and smart specialization.

5.2. Limitations and future research

Like other research, this research has some limitations. First, it is difficult to take into consideration every aspect of the RIS. The dynamics of the n-helix actors are very complicated, and differ region by region. There could be other variables, such as the views of foreign firms and research institutions and types of infused knowledge by linking international connections, that have not been taken into consideration in the current study. We recommend that future research investigates the international dimensions of RISs from the foreign institution and know-how transfer process perspective. Further, there could be additional factors that limit the transfer and spillover of knowledge in the region, such as social and cultural differences (e.g., norms, language, and routines), internal and external

actors' unwillingness to share and transfer knowledge, local firms' lack of learning intent, and the nature of knowledge (e.g., tacitness), etc. Future studies could investigate these factors that may curb the development of an RIS. For this study, we conducted interviews with a limited number of key knowledgeable individuals. Although they are the key representative RIS actors from the regional government, research institutions, and firms in Trentino, they might have unique perspectives and views on various RIS issues, and thus some interview quotes may reflect the specific points of view of the key informants. For this reason, our examination of this single case and our findings regarding the role of RIS actors and international connections should be interpreted with care. To resolve this, we recommend that future studies investigate various RISs by employing both qualitative and quantitative approaches as well as comparative research using our extended framework. Additionally, future studies could extend the identified relationships within the RIS to other contexts and especially to developing countries and peripheral regions. Even in a small region such as Trentino, the RIS benefits greatly from international connections. We recommend that future researchers develop an RIS map that shows both the local and international connections of the actors and how they impact on the regional development in different countries. Lastly, the integration of the stakeholder approach and boundary spanners approach (e.g., McAdam et al., 2012; Khan et al., 2015; Miller et al., 2016) into our suggested framework would provide additional insights on regional economic and social development.

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Figures and Tables

Table 1: Profile of interviewees

Type	Job title
Provincial government	Head of Department of Knowledge for Trento Province
	Director of Innovation and Development Department - provincial government agency
Regional firm	CEO of the Energy and Environment Cluster, comprising over 300 firms
	Owner of a textile (coated fabric) manufacturing company
University/research center	Head of Scientific Research and Transfer of Technology of the University of Trento
	Director of the technological unit of a regional research center

Table 2: Annual intramural R&D expenditure (in million euros)

Region	2008	2009	2010	2011	2012
Italian average	323.8	325.6	331.6	333.7	345.2
Northeast Italy	371.3	382.4	389.6	397.9	420.2
Trentino	**533.7**	**656.9**	**631.7**	**597.9 (1.71)**	**622.6 (1.83)**
Bolzano	201	199	207.1	235.3 (0.59)	224.9 (0.56)
Veneto	316.6	316.9	310.3	316.4 (1.02)	321.9 (1.06)
Friuli-Venezia Giulia	395.7	419.7	416.4	435.7 (1.48)	422.5 (1.45)
Emilia-Romagna	426.6	433.9	463.2	473.3 (141)	527.6 (1.6)

Figures in parentheses indicate the number of R&D personnel and researchers as a percentage of regional population in 2011 and 2012.

Table 3: Research expenditure as a percentage of regional GDP

Regions	2009	2010	2011	2012
Italian average	1.42	1.39	1.38	1.42
Northeast Italy	1.73	1.67	1.68	1.75
Trentino	**2.33**	**1.99**	**2.17**	**2.34**
Bolzano	0.86	0.84	0.87	0.84
Veneto province	1.63	1.52	1.51	1.53
Friuli-Venezia Giulia	1.96	1.75	1.77	1.85
Emilia-Romagna	1.82	1.88	1.87	1.99

Figure 1: Expenditure on R&D by institutions in Trentino (in million euros)

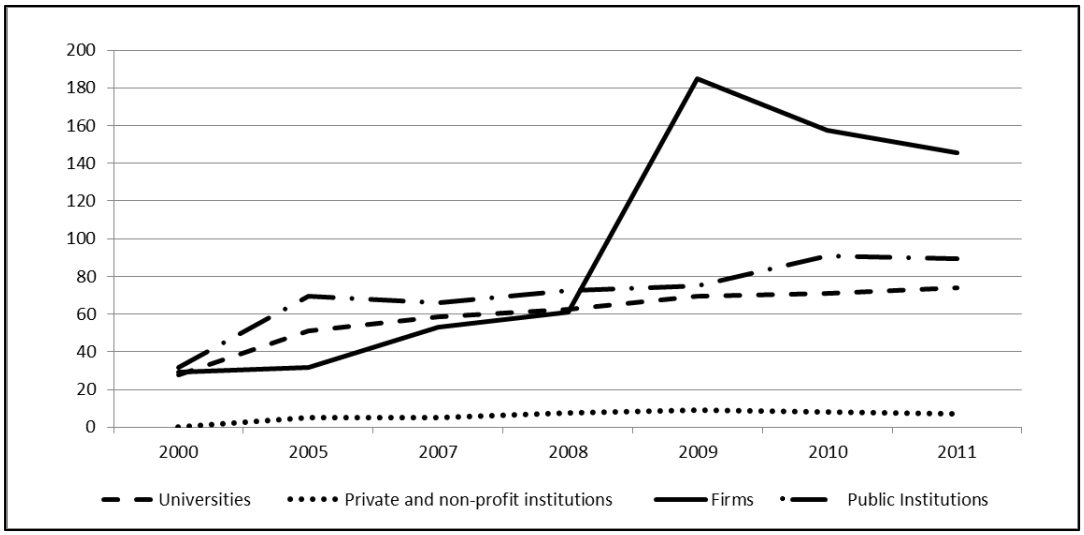

Table 4: Quadruple Helix: international connections as a complement to the Triple Helix

Roles of Triple Helix actors	International aspects
Provincial government	
✓Setup directives and the main rules and regulations. ✓Support and encourage the development of public-private partnership for innovation.	✓Policy for internationalization. ✓Funds for firms to attend international trade fairs. ✓Bonding and bridging functions of research centers in supporting local firms' internationalization and product and process innovations. **→ Providing fertile innovation and internationalization soils for the RIS**
University/research center	
✓Research publication and education. ✓Bottom up project with firms. ✓Close collaboration with regional firms. ✓Providing skilled human resources.	✓International research collaborations. ✓Faculty and student exchanges and visits. **→ Nurturing scientific knowledge into the RIS through international connections**
Regional firm	
✓Product and process innovation and continuous improvements. ✓Collaborations with firms and university and research centers.	✓Developing business networks with foreign firms and access to up-to-dated market knowledge. ✓Cooperation with international clients. **→ Reaping innovation outcomes of the RIS through international connections**