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Network Structures in Regional Innovation Systems

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Abstract:

While interactive learning and inter-organisational relations are fundamental building blocks in RIS theory, the framework is rarely related to investigations of regional knowledge network structures, because in RIS literature relational structures and interaction networks are discussed in a rather fuzzy and generic manner with the 'network term' often being used rather metaphorically.

This paper contributes to the literature by discussing theoretical arguments about interactions and knowledge exchange relations in the RIS literature from the perspective of social network analysis. More precise, it links network theoretical concepts and insights to the well-known classification of RIS types by Cooke (2004). We thereby exemplarily show how the RIS literature and the literature on regional knowledge networks can benefit from considering insights of the respective other.

Keywords: regional innovation system, network analysis, SNA, RIS.

JEL Classifications: O18, O33, R11, R12.

1 Introduction

The RIS framework is one of the most common and scientifically accepted frameworks for the analysis of regional innovation processes (Doloreux & Parto 2005). At its core, it is argued that regional actors do not innovate in isolation but that they are embedded in interrelated and interactive regional innovation processes. This interrelatedness and interactivity calls for the perception of regions as ‘innovation systems’ and implies that their innovation success depends on the innovative capabilities of regional actors and on the structure of their interaction (Doloreux 2002).

Hence, interactive learning and inter-organisational relations are fundamental building blocks of the RIS theory (Cooke & Morgan 1993; Cooke 1996). However, discussions and analyses of interaction structures among RIS organisations are still rare and usually limited to direct linkages between major actors (e.g. Koschatzky & Sternberg 2000) or focus on actors’ overall embeddedness (Dicken et al. 2001). In addition, studies in this field frequently discuss relational structures and interaction networks in a fuzzy and generic manner. In many instances, notions are used in a rather metaphorical manner in order to refer to relevant but by and large unspecified properties of the systems (e.g. Fischer et al. 2001; Asheim & Coenen 2005). For this reason, research on RISs generally lacks theoretically precise and quantitatively measurable statements about structures and characteristics of inter-organisational interactions and knowledge exchange relations (Grabher 2006; ter Wal & Boschma 2009). Ultimately, this ambiguity prevents RIS Research from developing clear-cut scientific hypotheses and policy recommendations with respect to one of its central building blocks.

We argue in this paper that the RIS literature can be enriched by insights from social network research, which are by and large still ignored in this literature (ter Wal & Boschma 2009). The paper’s objective is to show how typical arguments about interactions and knowledge exchange relations made in the RIS literature can be rendered more precisely by applying a network-theoretical perspective. Such allows for sharpening the RIS framework and for integrating an explicit ‘network dimension’ into the RIS framework.

The paper is structured as follows: Section 2 introduces and briefly discusses the RIS framework. In Section 3, the research focus is described, concepts from social network analysis (SNA) that help to translate terms frequently put forward in the RIS literature are introduced, and limits of the discussion are outlined. In Section 4, network-relevant statements made in the RIS literature are assessed against insights on interaction- and network-related aspects from network research. As a result, arguments about relational structures in the RIS literature are expressed in SNA terminology and key features of network-structures in RIS are derived. Section 5 concludes the paper and puts the findings into perspective.

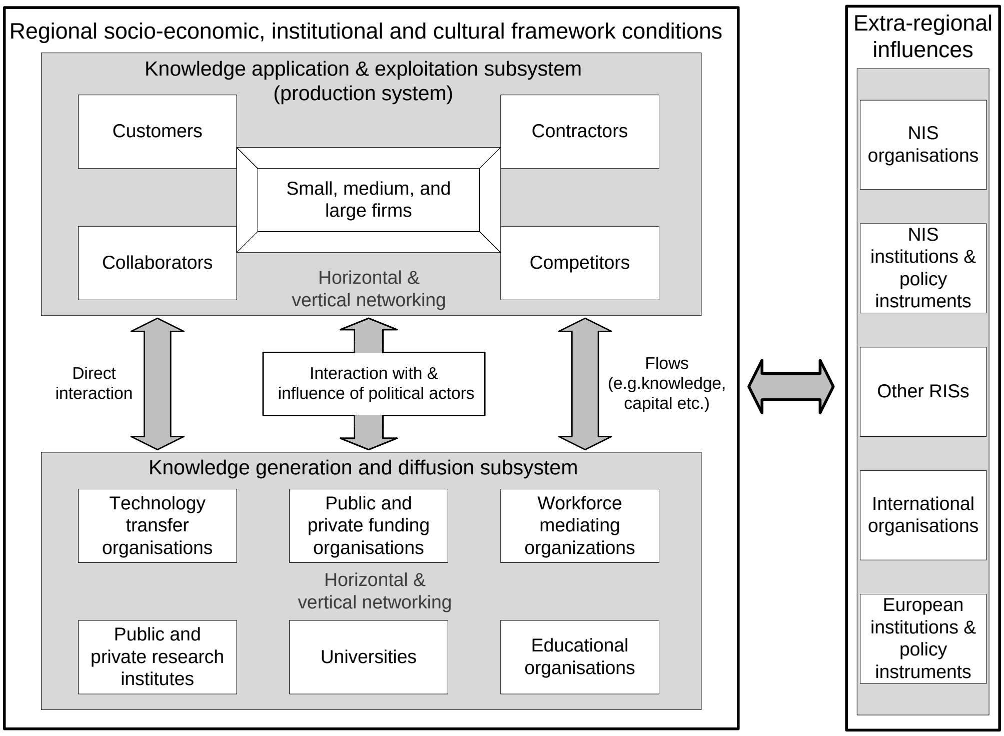
2 The Regional Innovation System framework and networks

2.1 The Regional Innovation System framework

The RIS framework is rooted in discussions about National Innovation Systems (NIS) (e.g. Freeman 1988) and developments linked to Post-Fordism (Amin 1994). According to Doloreux (2002, p. 244), its theoretical basis is based on heterogeneous research fields including evolutionary economics, institutional economics, (industrial) clusters, new regional economics, economics of learning, economics of innovation, and network theory.

The RIS framework highlights the regional dimension of innovation processes and emphasises how innovative and economic competitive advantages of regions relate to geographical proximity between actors, the way actors and institutions are spatially interconnected, and how RISs are constituted with respect to organisational and socio-institutional framework conditions.

Figure 1: Schematic illustration of a Regional Innovation System



Own illustration based on Autio (1998, p. 134) and Cooke (2002, p. 137).

As shown in Figure 1, a RIS constitutes a system of interacting actors (bright boxes) and subsystems (dark boxes). Usually, such actors are understood as organisations. From a theoretically idealised point of view, organisations within a RIS belong either to the knowledge application and exploitation (i.e. firms and customers) or to the knowledge generation and diffusion subsystem (i.e. support organizations, public administration, educational organizations). Actors from the former sub-system are the major drivers of commercial innovation activities in a RIS and thus of vital importance. Actors from the latter subsystem conduct business sector supporting activities and engage in the production and dissemination of knowledge and skills (Autio 1998). The framework also imputes that public and especially political actors may have a substantial influence on the RIS by generating incentives, upgrading infrastructures, developing technological alternatives, promoting emerging technological systems, and supporting collaboration activities (Lundvall & Borrás 1997; Fornahl & Brenner 2003).

According to this description, RISs are generally described as "*interacting knowledge generation and exploitation subsystems linked to global, national and other regional systems*" (Cooke 2004, p. 3) "*in which firms and other organisations are systematically engaged in interactive learning through an institutional milieu characterised by embeddedness*" (Cooke et al. 1998, p. 1581). RISs thus constitute the supporting institutional, organisational and technological infrastructure within a regional production system.

Interdependent linkages – resulting from diverse types of interactions – within and between the actors and subsystems as well as between the region and the outside world form the system-creating fundament (Uyarra 2011). Such linkages usually imply interactive learning, cooperation, and knowledge exchange activities that ensure external expertise, efficiency gains, and reduction of uncertainties (Dodgson 1994). The institutional milieu consisting of e.g. regional rules, attitudes, standards, and values shapes the strength and working of these linkages (Cooke et al. 1997). The milieu and its effects are region- and context-specific (Gertler 2010) making regional innovation systems difficult to duplicate (Doloreux 2002).

A supportive milieu will ease the coordination of knowledge-related interaction and joint projects and hence support the creation and maintenance of links between regional actors, which in turn stimulates inter-organisational knowledge spillovers. These spillovers facilitate regional knowledge generation and diffusion, which ultimately increases the RIS's innovation performance (Camagni 1991; Bathelt et al. 2004).

Ever since the pioneering works of Cooke (1992) and Cooke & Morgan (1994), one of the major fields of RIS research is to elaborate on how RISs are structured and how they function. The prime foci are thereby their institutional and organisational dimensions (e.g. Cooke et al. 1997; 1998), their evolutionary character (e.g. Cooke et al. 1998; Fu 2011), governance and policy aspects (e.g. Cooke et al. 2000; Antonelli/Quéré 2002; Cooke 2007), the importance of firms, higher education institutions (HEIs)[1], and research institutes for RISs development (e.g. Revilla Diez 2000; Muller & Zenker 2001; Revilla Diez & Berger 2005; Caniëls & van den Bosch 2011), and to what extent RISs exist in different types of regions (i.e. metropolitan areas, old-industrial regions, regions in transition, etc.) (e.g. Asheim & Isaksen 1997; Kaufmann & Tödtling 2000; Revilla Diez 2002b; Doloreux & Dionne 2008).

The vast majority of empirical studies in this field describe how innovation processes are organised and how this relates to different organisational, institutional, and political conditions. However, much less attention has been paid to the actual role and structure of RIS internal and external interactions with respect to innovation processes. Contributions that discuss the relevance of interactive behaviour and networking for RISs are Cooke & Morgan (1993), Cooke (1996), and Fornahl & Brenner (2003). These authors underline the general importance of regional networks and interactions as well as the relevance of relations between specific types of innovating actors such as HEIs and firms. These insights are rendered more precisely by empirical studies, which usually employ methodologies targeted at the investigation of selectively chosen, direct relations between actors or subsystems (Koschatzky & Sternberg 2000; Revilla Diez 2000, 2002a).

2.2 RIS and a network perspective

However, the existing theoretical and empirical studies so far neglect at least two inherent features of RISs as a representation of a complex system of interrelated and interdependent organisations: indirect relations and structural characteristics of the complete system of (*direct and indirect*) relations. Indirect relations refer to the idea that two organizations that do not interact directly may still be (indirectly) related, as organizations they (directly or indirectly) interact with might be linked by interaction. The literature on knowledge networks shows that such indirect relations are crucial for knowledge diffusion and innovation (e.g. Grabher 2006; Glückler 2007; ter Wal 2011). Given the relevance of indirect relations, structural characteristics of the complete system of relations (i.e. the network) become important as well. In fact, many of the central concepts in network research rely on the relevance of

[1] HEIs are universities, applied universities, polytechnical universities or the like.

indirect linkages (for an overview see e.g. Wasserman & Faust 1994).

In addition, RIS-related literature often suggests that all organisations within a RIS (and independently of a specific type of RIS) benefit equally from regional knowledge spillovers (e.g. Asheim 1994; Cooke 2001a). This is based on the assumption that due to geographic and socio-institutional proximity all actors are part of extensive regional networks (Boschma & ter Wal 2007). This argument implies that all regional actors are similarly embedded in regional networks and that network structures hardly vary between regions and RIS types. However, insights from network research clearly conflict with this view. To the contrary, they suggest significant heterogeneity in the embeddedness of organisations into regional networks (Giuliani & Bell 2005; Boschma & ter Wal 2007) as well as heterogeneous regional network structures (Fleming et al. 2007). Both aspects have essential implications for knowledge diffusion and thereby for innovation activities in RIS, which have however rarely been discussed.

In summary, by ignoring indirect relations, heterogeneous network embeddedness, and structural characteristics of regional networks within a RIS, significant portions of the system-character of RIS remain unexplored. In other words, without adding a network-oriented perspective that includes these aspects, RIS as 'systems of interactive elements' cannot be fully understood.

The question remains, why these features have not played a more prominent role in RIS research? While it is beyond the scope of the present paper, it appears feasible to speculate that it is primarily the insufficient network-theoretic foundation of the RIS concept that has prevented an explicit analysis of regional network structures within this framework. More precisely, and this will be shown in more detail later in this paper, most theoretical statements about interactions and networks in the RIS framework are vaguely formulated and do not allow for precise conclusions on regional structures of interactions (Grabher 2006; ter Wal & Boschma 2009). This may in parts be related to the "fuzziness" that has been attributed to the RIS framework in general (Markusen 1999). In addition, the RIS framework has been developed by geographers, which were not familiar with network concepts and methodologies developed in sociology and mathematics in the past. It may even be the case that the rather quantitative nature of SNA did not appear to be very attractive for many geographers in the 1990s and early 2000s, who rather applied qualitative research strategies in their empirical studies. As a result, few RIS studies exist that explicitly focus on interactive behaviour in innovation processes and do appear to be out-dated (ter Wal & Boschma 2009; Uyarra 2011).

The aim of the present paper is a first attempt at integrating some theories and concepts of network research into the RIS framework. Hence, we follow ter Wal & Boschma (2009) and argue for enriching the RIS framework with an explicit theoretically derived "network dimension". Such may allow for the development of empirically testable hypotheses regarding network structures in regional innovation processes of RISs in the future.

It is, however, also important to point out that an integration of the network perspective into the RIS framework will also add to the literature on knowledge networks. This particularly regards the rich insights of RIS research on institutional and governance factors influencing economic actors' interactions.

3 Scope of discussion

3.1 Defining the object of analysis – Cooke's RIS framework and network-theoretical concepts

Given the heterogeneity of the RIS literature and its size (for an overview see e.g. Doloreux 2002), we have to limit our discussion to a particular stream within the RIS literature, namely the RIS framework as proposed by Cooke (1998; 2004). This concept is probably most widespread and its main statements about relational structures and networks in RIS can be found in the other RIS literature streams in a similar manner.

Cooke's RIS framework differentiates between two analytical dimensions – the *Governance Innovation Dimension* (GID) and the *Business Innovation Dimension* (BID). According to Thomi & Werner (2001), the BID especially depicts major characteristics and structures of innovating actors as well as their spatial organization. The GID captures how innovation processes are managed and controlled.

Figure 2: Types of Regional Innovation Systems

Business Dimension \ Governance Dimension	Grassroots	Networked	Dirigiste
Globalised	Globalised grassroots RIS	Globalised networked RIS	Globalised dirigiste RIS
Interactive	Interactive grassroots RIS	Interactive networked RIS	Interactive dirigiste RIS
Localist	Localist grassroots RIS	Localist networked RIS	Localist dirigiste RIS

Own illustration based on Cooke (2004, p. 15)

The framework distinguishes three models within each of the two dimensions (see Figure 2). In the BID, these are the interactive, the localist, and the globalised model. In the GID the classification includes a grassroots, a network, and a dirigiste model. By combining both dimensions Cooke (2004) identifies nine theoretical RIS types. Those RISs located on the diagonal of the matrix (darker boxes) can be seen as most *'ideal types'* of cases, as their characteristics are most clearly distinguishable. They are therefore chosen to form the basis for the following discussion. That is, we collect and evaluate arguments, empirical facts, and hypotheses put forward in the literature for each of these three types concerning formal and informal regional knowledge interactions and collaborations. Hence, the discussion will also be limited to inter-organisational knowledge exchange relations involving the most important R&D performing actors. Besides keeping the task manageable, the second limitation also corresponds to what is usually investigated in the network-related literature in the field of Economic Geography.[2] We leave it to future research to expand this discussion to additional RIS types and other types of interaction.

[2] This particularly concerns formal and informal collaboration in R&D. However, labor mobility, joint R&D work, and unintended knowledge spillover may also be included.

3.2 Defining the object of analysis – network-theoretical concepts

With respect to network research, we concentrate on a number of simple but common concepts that are presented in the following.

Network Size and Density

Networks are based on nodes that are connected by links. Two fundamental characteristics of networks are their size and density. The number of nodes (i.e. actors) commonly defines *network size*. The density of a network is estimated as the ratio of the number of observed and the number of theoretically possible links given the number of nodes n. In the context of this paper, size corresponds to the number of organisations within a region that may potentially establish knowledge exchange relations. The *network density* is closely related to its size, as the probability that all theoretically possible combinations are realised usually decreases when the number of nodes grow (Jansen 2003). This can be explained by the limitations in an individual node's capacity to initiate and maintain links to other nodes, which is particularly the case when links imply some kind of social relation. Hence, size may represent the maximal potential for interaction, while density is a general indicator of how quickly information, knowledge, and innovation will be disseminated within a network (Jansen 2003, p. 94).

Centrality and Centralization

Centrality captures which "[...] *actors are those that are extensively involved in relationships with other actors*" (Wasserman & Faust 1994, p. 173). It is used to describe nodes' positions within networks and generally represents their influence and relevance. A number of different concepts of centrality have been developed in recent decades (for an overview see e.g. Borgatti & Everett 2006). Among the most important measures are degree and betweenness centrality (Freeman 1979).

Degree centrality is a node's number of direct links to other nodes. In contrast, betweenness centrality is more complex, as it considers indirect links as well. It is based on the idea of *shortest paths* (also known as *geodesic distance*), which is the minimum number of 'steps' along the network to reach another node. A 'step' corresponds to a direct link between two nodes. Based on this idea, *betweenness centrality* describes a node as being central when a large number of shortest paths in the network include the focal node (for more details see Wasserman & Faust 1994). Both centrality measures differ in their meaning. Degree centrality is a measure for a node's local centrality and general embeddedness into the network. Nodes with large degree centrality have a large influence on their direct surroundings (directly linked nodes) and their network embeddedness is robust and resilient to external shocks. Nodes characterized by large betweenness centrality hold ‘broker positions’ within a network. For instance, in knowledge networks information are most likely to diffuse along shortest paths through the networks, which puts organizations with large betweenness centrality in the position to control the diffusion process (Graf 2011).

On the basis of these two concepts, it is also possible to derive measures of networks’ overall centralization. Centralization allows for conclusions regarding the macro-structure of a network. For instance, the most centralised network is a star-shaped network in which all connections are focused on one node, which implies that the degree and betweenness centrality of the dominant node is at its maximum. In practice, the centralization of networks is evaluated by comparisons with such a theoretically maximal centralised network structure. Networks with a low centralization are usually seen to be non-hierarchical while the opposite holds for highly centralised networks (Wasserman & Faust 1994). In addition, the centralization of a network and the distribution of centrality among its nodes is a rough measure of network *robustness*, which refers to the resilience of a network’s structure to the event of node disappearance (Cowan & Jonard 2007). The more a network is centralised around one or few nodes the higher the likelihood that its structure will change when the most central nodes disappear. Centralised networks are hence more prone to structural change, as they are less robust in their structure.

Related to the centralization of a network is its *fragmentation*. Fragmentation refers to the number of components in a network. A component consists of at least two nodes that are at least indirectly connected. A highly fragmented network accordingly has many components. In other words, a number of sub-networks (components) exist, of which each node is at least indirectly linked to all other nodes in the component, while none are linked to a node in another component. Fragmented networks are more robust to node disappearance, as each node’s relations matter only for the component it is part of.

Hierarchy and Network Structure

Network research has identified a number of network structures with specific implications for knowledge diffusion and power structures among the members of a network. Two of the most prominent are the small-world type and the core-periphery type network.

The idea of *small-world type network structures* dates back to Milgram (1967). Based on that, Watts & Strogatz (1998), Watts (1999a, b) and Barabási & Albert (1999) made significant contributions to the formalization of the small-world phenomenon.

A small-world network is characterised by a high degree of ‘clustering’, i.e. the frequent presence of at least three nodes that are completely linked (also called a ‘clique’). These cliques tend to be connected by few links. Moreover, these networks show a distribution of degree (centrality) values similar to that of a power-law function: few nodes are characterised by high centrality and many by low centralities. Small-world structures generally support an efficient diffusion of knowledge in the network, as even large networks with low density may obtain low node-to-node distances (low average shortest path length). A large number of structural holes (Burt 1992) exist in these networks also providing sufficient potential for novelty creation (Cowan & Jones 2004). Moreover, as nodes linking cliques hold prominent broker positions (high betweenness centrality), the network is characterised by a strong power hierarchy (Ravasz & Barabási 2003).

The most popular definition of *core-periphery structures*[3] can be found in Borgatti & Everett (1999).[4] According to these authors, a network has a core-periphery structure if its nodes can be partitioned into two sets: the core and the periphery. Nodes in the core are strongly linked among themselves. In contrast, nodes in the periphery are sparsely interlinked. Frequently, nodes in the periphery are either isolates (no links at all) or weakly linked to the core nodes. If networks qualify as core-periphery networks their nodes are in a hierarchical order with those belonging to the core being more powerful and influential than nodes in the periphery. In contrast to small-world type networks, diffusion tends to be less efficient in this network.

Regional (inter-)connectivity

In addition to network structures among regional actors, the degree of the *connectedness of regional actors to extra-regional actors* regarding knowledge and innovation generating processes is also crucial for regional innovation activities (Bathelt et al. 2004). Broekel et al. (2011) and Broekel (2012) empirically show that the intensities of interaction among regional actors and between regional and extra-regional actors need to be balanced to yield positive effects on regions’ innovation performance.

Related to this is the discussion about regional ‘*gatekeepers*’ (for an overview see e.g. Provan et al. 2007). Gatekeepers are central actors within a regional network that additionally link the regional to extra-regional networks. Gatekeepers ensure access to (new) knowledge from outside the region, which they help to diffuse within the region. They also broker these

[3] The here elaborated core-periphery structure should not be confused with the core-periphery model developed and discussed in fields of Economic Geography by researchers like e.g. Friedman (1973).

[4] Other and somewhat stricter definitions can be found e.g. in Bramoullé (2007).

knowledge flows to some extent, giving them a crucial position in regional knowledge networks (Graf 2011).

4 Regional Innovation System types from a network perspective

In the following, we will use the network-theoretical measures to evaluate and render more precisely the arguments made in the RIS literature on knowledge relations and networks in the three (localist-grassroots, interactive-network, globalised-dirigiste) types of RIS.

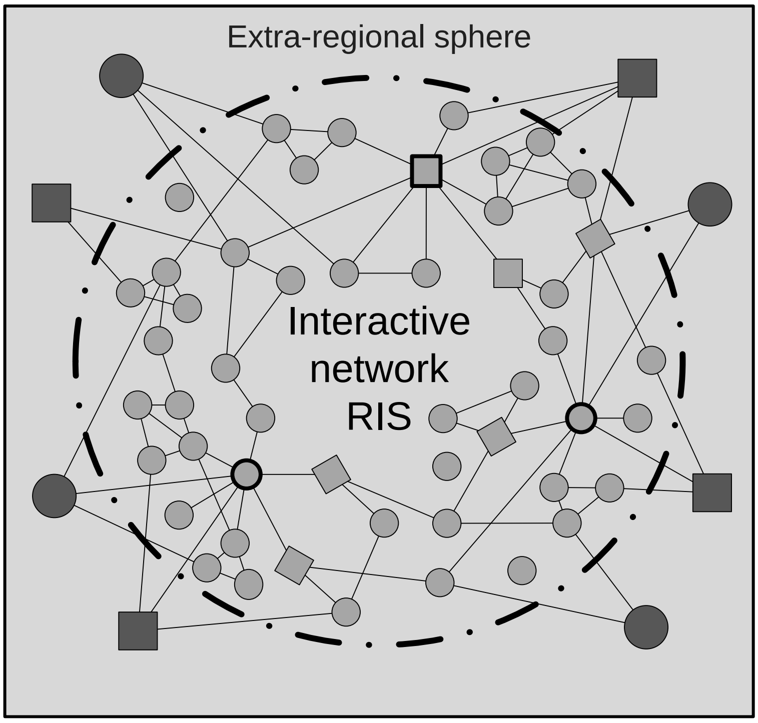
4.1 Interactive Network RIS

From a normative perspective an interactive network system is universally regarded as the most ideal RIS type. The GID of such a RIS has a so-called 'network' modality, which implies a multi-level approach with regard to both policy and business governance. Policy governance is located at all territorial levels (regional, national, and supranational) and its measures are well-designed and soundly applied. With respect to business governance, innovation management and coordination are similarly distributed, thus showing a mix of local, regional, and inter-regional influences (Cooke 1998, 2004).

The BID's 'interactive' modality of this RIS shows a relative balance between small and medium-sized enterprises (SMEs), as well as large firms (domestic or foreign-owned), with the majority of firms being engaged in R&D. The R&D activities are predominantly focused on advanced or high-tech sectors. Usually, numerous research entities (i.e. HEIs and research institutes) exist in such RIS, supporting firms' R&D activities. Nevertheless, the profit-oriented private sector is the clear driving force in the system with the (public) research sector playing a supportive role (Beise & Stahl 1999; Caniëls & van den Bosch 2011). In general, the propensity for collaboration between regional actors is very high, as technological sophistication of organisations is associated with strong efforts to participate in knowledge networks. Moreover, these R&D activities are embedded in well-developed regional institutional infrastructures (Cooke et al. 2004).

In addition to the intense regional collaboration characterising this RIS, many regional actors (public and private) are well connected to extra-regional actors, as they "[…] *cannot rely only on localized learning, but must also have access to more universal* [(i.e. extra-regional)], *codified knowledge* […]" (Asheim & Isaksen 2002, p. 84). Hence, an interactive network RIS corresponds to a significantly sized agglomeration of public and private organisations that interactively engage in R&D on the regional as well as on the national or international level.

<u>Figure 3:</u> Schematic illustration of knowledge networks in an Interactive Network RIS



Own illustration; circles=firms, squares=HEIs and research institutes, bolded circles/square=most central actors, dot-dashed circle=RIS.

Due to their interactive set-up it is probable that – compared with other RIS types – the regional nodes are likely to be more extensively embedded in the regional knowledge network and that many of them are additionally engaged in extra-regional relations. Moreover, the vast majority of actors engage in regional interaction. Figure 3 illustrates these arguments schematically.

The first insight that can be gained from applying the network perspective to this RIS type is that its conception does conflict with the previously outlined negative relationship between network size and density; accordingly, relatively low densities characterise large networks. The description of the interactive network RIS implies a large number of interacting actors in absolute (many actors) as well as in relative (few isolates) terms. Hence, this RIS can be expected to show a large regional network (i.e. large number of nodes) with an above-average number of linkages. However, its density is likely to be relatively low because density tends to decrease, as the number of interacting organisations in the RIS exceeds the average capacities of actors to initiate and maintain links. This capacity can be expected to be rather medium given the RIS's balanced mix of SMEs with small capacities and large firms with above-average capacities. In addition, parts of this capacity are moreover invested in inter-regional linkages, which are argued to be well-developed in this RIS. In sum, network theory suggests that the network of this RIS is of lower density than in other regions.

Another feature of this type of RIS is that its actors differ in terms of reputation and absorptive capacities. To a large extent this is related to size differences (Cohen & Levinthal 1990; Giuliani & Bell 2005). Given that the business sector is argued to play the most important role for knowledge generating activities in this RIS, it can be expected that large firms hold most of the central positions, i.e. they are most central in terms of degree and betweenness centrality (see Figure 3). However, their number is relatively limited, which leads to the expectation of a rather low network centralization in general.

The prominent position of these actors puts them into broker positions (high betweenness centrality) that integrate the network. That is, these firms link otherwise unconnected parts of the network, which primarily include SMEs and research entities. They thereby impose a hierarchical network structure. In particular (public) research organizations contribute significantly and actively to knowledge production and diffusion in this type of RIS (Cooke 1998, 2004). We therefore argue that these are characterised by higher degree and betweenness centralities than SMEs.

All these outlined features – the unequal distribution of network centralities, the large size of the network paired with a relatively low density have important implications for the capacity of a RIS to diffuse knowledge among its organisations. For instance, the institutional settings of the RIS have to ensure that the most central firms actively play their role as knowledge brokers. However, the relatively low density of the network still implies a relatively low knowledge diffusion capacity (Cowan & Jonard 2004). Such contradicts the above described characteristics of this RIS internal network. This contradiction between RIS characteristics and network mechanics can only be dissolved by a network structure that combines low density, unequal node centralities, (still) high diffusion properties, and a large potential for novelty creation (i.e. structural holes). As pointed out above, a network structure with such features is a small-world type network. Besides the leading firms being most central, this structure requires an unequal degree distribution, which can be related to the existence of preferential attachment processes.[5] The (public and private) support organisations also need to form groups of strongly interlinked actors, which corresponds to clustering processes in network terminology (Watts & Strogatz 1998). Moreover, the development of a small-world type structure also requires that interaction between the densely linked groups of support actors is rare and most of the between group interaction is provided by the leading

[5] Preferential attachment implies that new actors tend to connect to the most central actors (in terms of degree) in the network first (Newman 2001a).

firms, which thereby integrate the otherwise unconnected parts of the network. Initial empirical evidence points in this direction (e.g. Nakano & White 2006), thereby supporting our hypothesis of small-world type network structures characterizing the knowledge network in an interactive network RIS.

Despite the relatively small number of actors holding central positions in the network, the small-world network structure is relatively robust (Cowan & Jonard 2007). Even in case a single central actor fails or vanishes for whatever reason, the greatest part of the network will remain intact (Watts 1999a; Albert & Barabási 2002). The reason is the strongly clustered network structure in the vicinity of this organisation, which is likely to remain and continue to connect other parts of the network. In this sense, if small-world-network structures are present in this type of RIS, these are well suited to absorb failures of central nodes, which contributes to the temporal stability of this type of RIS.

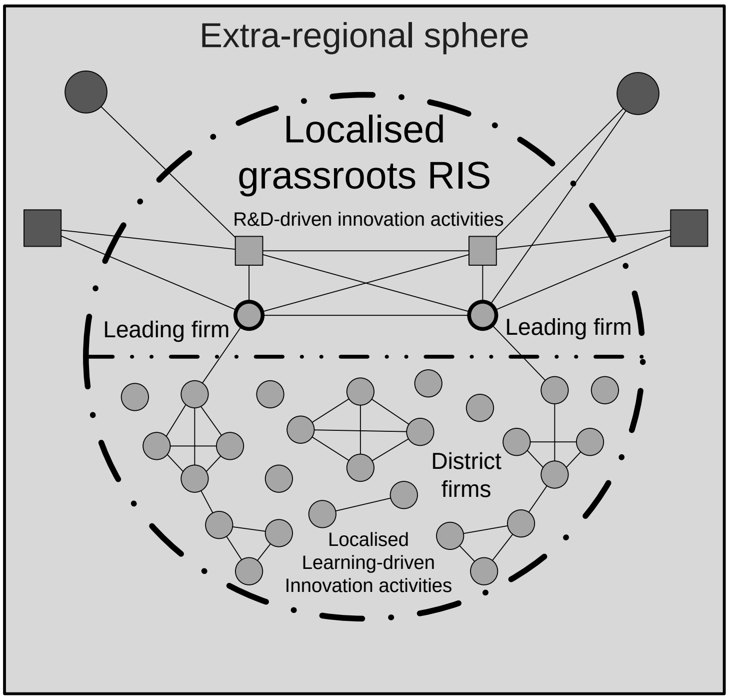
However, it is not yet clear whether small-world-network structures in regional knowledge networks actually fit to above average regional innovation performances attributed to interactive network RIS. However, the empirical evidence is still inconclusive (Fleming et al. 2007; Breschi & Lenzi 2011). Clearly, more research on this issue is needed in the future.

4.2 Localist Grassroots RIS

The 'grassroots' modality of the localist grassroots RIS's GID means that policy and business governance are predominantly organised at the regional level. Innovation activities are thus largely controlled and managed by regional actors (Cooke 1998, 2004). The 'localist' modality of this RIS's BID usually comes into existence because of one or more small-scaled industrial districts being located in the region. The districts are characterised by regional inter-firm learning processes in a neo-Marshallian sense (e.g. Best 1990). Their firm population is dominated by SMEs, which are hardly involved in R&D. Consequently, R&D related knowledge relations are generally rare, as most district firms are, if at all, interested in spontaneous, industry-specific, and practical support (Asheim & Coenen 2005). Lacking R&D, the SMEs remain competitive through flexible production, specialisation, strong division of labour, and innovation processes based on tacit knowledge. Hence, compared to other RIS types, the localist grassroots RIS hosts a relatively small number of R&D performing actors (Cooke 1998, 2004). However, a few 'leading firms' active in R&D or larger research entities tend to be present in this type of RIS (Morrison & Rabellotti 2009; Munari et al. 2012). These are active in advanced or even high-tech R&D (Coletti 2007). Naturally, these actors dominate regional R&D activities in terms of capacities and knowledge exchange. With respect to the latter, their primary sources for new knowledge are region external contacts (e.g. Morrison & Rabellotti 2009). Within the region, they are nevertheless strongly linked to each other (e.g. Rabellotti 1995; Curzio & Fortis 2002). In contrast to research entities, leading firms also maintain some relations to regional SMEs (Stokman & Docter 1987). These leading firms therefore function as sorts of 'knowledge translators' for the rest of the district or cluster by absorbing, decoding, and diffusing knowledge from within and outside the district (Morisson 2008). In doing so, they integrate various groups of organisations and subsystems of the RIS (Asheim & Coenen 2005). Figure 4 schematically summarises these arguments.

Applying the network perspective and its terminology in accordance to the above descriptions, the following can be derived. The hierarchical structure of regional knowledge relations (leading firms – research organizations – SMEs) in combination with the segregation between SMEs and research entities suggests a strong fragmentation of the knowledge networks. Many SMEs may even remain unconnected to the regional knowledge networks due to the lack of R&D and knowledge capacity constraints. The large number of isolates adds further to the networks' fragmentation. The fragmentation is partly overcome by leading firms playing the role of gatekeeper organisations. These also connect the region to cross-regional knowledge networks.

Figure 4: Schematic Illustration of Knowledge Networks in a Localist Grassroots RIS



Own illustration; circles=firms, squares=HEIs and/or research institutes, bolded circles=most central actors, dot-dashed circle=RIS.

Knowledge networks in an ideal-typical localist grassroots system are likely to be small in terms of the number of nodes (i.e. organisations). Due to the system's localist BID set-up and the predominantly regionally oriented interaction activities it is most probable that − compared to other RIS types − the regional nodes show an above-average share of regional knowledge links. Simultaneously, the distinct multi-component structure of the regional network tends to show similarities to the previously discussed core-periphery model. The core-periphery network structure mirrors the RIS's distinct hierarchical structure because the periphery (SMEs) is dependent on 'translation activities' of the core consisting of the leading firms and some research organizations. The separation of the core and periphery is indicated in Figure 4 by the 'dash-point-point-dash' line in the middle of the large circle.

A core-periphery structure has severe consequences for the application of other network related measures. For instance, the average density of the network is less interesting, as there are two parts to the network: The organizations in the core are densely interconnected implying large network density while the periphery is only sparsely interlinked and characterized by low network density.

Organizations in the core are clearly superior in terms of degree centrality. A localist grassroots RIS will therefore show a bimodal degree distribution with few organizations (core) having large degree centralities and many organizations (SMEs in the periphery) with low to medium centrality values. In addition, nodes in the core with connections to actors in the periphery will be dominant in terms of betweenness centrality. This is not to say that actors in the periphery do not cooperate in R&D at all. While they are weakly interconnected, they may still form some small network components (Giuliani 2007; Morisson & Rabellotti 2009).

Due to the core-periphery structure it is difficult to make predictions about the centralization of the entire network. We nevertheless expected overall centralization being between that of the interactive network and the globalized dirigiste RIS (presented in the next subsection). The reason is that R&D-related knowledge exchange relations in a localist grassroots RIS are more concentrated on a small number of central actors than those in an interactive network RIS. This leads to higher overall network centralization in a localist grassroots RIS than in an interactive network RIS. In contrast, interactions in a localist grassroots RIS are less concentrated than in a globalised dirigiste RIS because its R&D-related knowledge exchange relations are not focused on a single dominant organization as it is the case in the globalised dirigiste RIS.

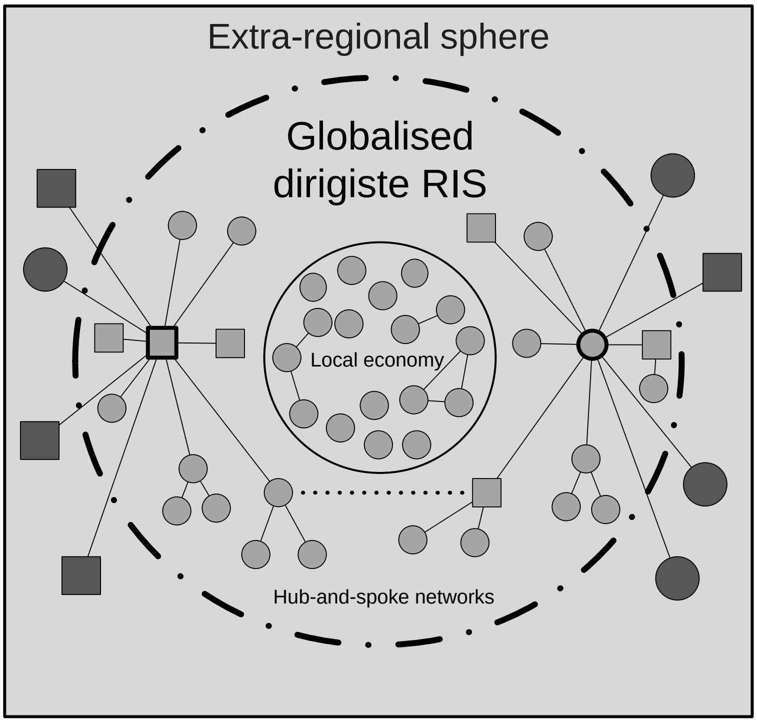
Despite the higher centralization, the robustness of this RIS's network structure in general and of the core in particular can be expected to be relatively high, since both are extensively connected. This means that in case of node failure out the other nodes will remain strongly interconnected. The 'weak spots' of the structure are the few organisations connecting the core and the periphery. If one of these fails, the integration of the complete knowledge diffusion system between the core and the periphery will be significantly disturbed (Callaway et al. 2000).

4.3 Globalised Dirigiste RIS

The 'dirigiste' modality of this RIS type's GID emerges from strong influences and control from outside the RIS. Accordingly, region-external actors (e.g. central governments) make decisions on regional matters in a top-down style (Cooke 1998, 2004). The system's BID is shaped by the existence of one or more (industrial) districts, such as high-tech clusters, science parks, etc. These usually centre on a large organisation's headquarter (HQ) or on a subsidiary of a large multinational enterprise (MNE), which is very active in R&D. In some cases, large governmental research organisations and their institutes may play a similar role as well (Asheim & Isaksen 2002). The overwhelming importance and economic weight of such large actors (so-called 'focal actors') induces a 'globalised' modality, as these actors' R&D activities are directed to region external innovation processes (Cooke 1998; Asheim & Isaksen 2002). The surrounding organizations in the district, SMEs or small local research organizations, play primarily supportive roles (Cooke 1998, 2004). The focal actor clearly dominates regional knowledge exchanges implying that the network is organized according to its needs (Lorenzen & Mahnke 2002; Cooke et al. 2004). That is, for instance, this organization defines the directions of research and selects its collaboration partners. When the focal actor is a subsidiary of a region external organisation, actors outside the region sometimes make such decisions.

At the same time, the focal actor ensures necessary, non-regional knowledge flows into the district through their embeddedness in global networks. If a RIS is characterized by more than one district with a focal actor, local interactions between the focal actors are possible, even though interaction activities always depend on firm- and industry-specific characteristics and the willingness of the respective organisations to collaborate (Markusen 1996).

<u>Figure 5:</u> Schematic illustration of knowledge networks in a globalised dirigiste RIS



Own illustration; circles=firms, squares=HEIs and/or research institutes, bolded circle/square=most central actors, dot-dashed circle=RIS.

In addition to the strong outward focus of the focal actor, it is the lack of other district members participating in regional knowledge networks that makes the districts' networks relatively isolated from the remaining regional economy (Henry et al. 1995). There are multiple reasons for this. In many cases, it is however a simple mismatch between industrial, organisational, and institutional conditions. Such mismatches typically arise when the hub organization is (too) strongly oriented towards region-external networks or when the entire RIS is subject to strong top-down interventions by national or supranational policies (Markusen 1996; Cooke 2001b).

Figure 5 illustrates schematically the networks of an ideal-typical globalised dirigiste RIS. The small circle in the middle represents the regional economy that is by and large unconnected to the industrial districts. The two star-type structures on the left and right visualise the industrial districts with its core member (focal actor) being strongly embedded in region-external networks (lines crossing the thick dot-dashed circle).

With its focal actor and the surrounding smaller support organisations, a globalised dirigiste RIS is likely to entail hub-and-spoke structures as elaborated by Markusen (1996). These structures translate to regional knowledge networks with the hub being the focal actor and the other actors (spokes) being organised similarly to a chariot wheel as depicted in Figure 5. The hub-and-spoke structures also give rise to distinctive ‘depth’ hierarchies of power and governance with the hub organisation being at the top of a ‘pyramid’ and numerous, subordinated suppliers are ordered at different levels below (Nakano & White 2006).

By its very nature, the hub has a very large absolute number of cross-regional links, while the supportive organisations are characterised by low numbers. These outside relations are more crucial for this RIS than regional ones. However, we still apply the network perspective to this RIS type with an exclusive focus on the region internal knowledge network in order to stay consistent with the other cases.

The size of the intra-regional network(s) can range from very small to large depending on the number of hub organisations (i.e. focal actors) and the size of the respective districts they are heading. The number of networks mirrors the number of hubs, which are, however, unlikely to exist in great numbers. In the case of two or more hub organisations, the network of the RIS will have multiple fragments. Each fragment represents a network surrounding a hub organization. These networks are strongly subject to a hierarchy effect with the hub organization heading a network with near star-type structure (see Figure 5). The length of the rays depends on the hierarchical structure of the hub’s regional knowledge network and on the number of value-chain stages that district organisations contribute to. Nakano & White (2006) suggest that subcontracting in local networks of multinational enterprises fosters the emergence of complex supplier networks, which may exhibit small-world features. However, this requires significant collaboration among the subcontracting SMEs, which are usually rare when hub-and-spoke type structures are ideal-typically developed. The density of the overall RIS network will be relatively low due to the dominance of star-type sub-networks. This holds even in case of multiple hub organisations being present (which is rarely the case (Markusen 1996)), as they tend to be weakly interlinked.

Obviously, the hubs are characterised by superior degree centralities. Given that all other organizations maintain a limited number of links, we can expect a bimodal degree distribution whereby the number of hubs defines the magnitude of the second mode. The hub organizations also qualify as gatekeepers for the rest of the region, as they are the only actors that link the region’s (or district’s) internal networks with actors outside the region. However, the hubs do not necessarily dominate in terms of betweenness centrality, as it might be the case that smaller regional actors are able to simultaneously link to multiple hub-headed-networks. Such smaller regional actors are not hubs themselves but most likely (public) research institutes or HEIs located in the region. They are able to offer services and knowledge to different industries and hence establish relations to different sub-networks

(Kroll et al. 2012), which are indicated through the dotted line in the middle of Figure 5. When existent, these actors will show the highest values in betweenness centrality, which otherwise will be the case of hub actors.

When a globalised dirigiste RIS is formed around a single or few hubs, its network is highly centralised and exhibits the largest network centralization of all RIS types. Centralization will naturally decrease with the number of hubs in the system. Isolates are not typical within a network characterised by hub-and-spoke structures.

Hub-and-spoke networks are particularly vulnerable in case a hub ceases to exist (e.g. closing or relocation). In case of such an event, the RIS's network or at least that of the respective district (if more than one hub is present) will lose its integrative force and completely dissolve. The event goes hand in hand with significant reductions in access to inter-regional knowledge pipelines (Bathelt et al. 2004). However, if more than one hub exists, the other districts and their network components will remain intact. Accordingly, the overall robustness of the network depends on the number of hub organisations und districts present in the region.

It is important, however, to point out that globalized dirigiste RISs have at least one component that does not show the described hub-and-spoke characteristics. This component represents the network of the regional economy outside any hub-headed district (in Figure 5, small circle in the middle). Given the low relevance of these organisations for innovation activities in the region, it will be neglected at this point.

5 Conclusion

The aim of this paper was to apply a network perspective to the RIS framework, as the latter strongly relies on the conceptual basis of networks but so far lacks a clear network theoretical discussion (Grabher 2006; ter Wal & Boschma 2009).

Table 1: **Summary of Knowledge Network Characteristics in Different RIS Types**

Knowledge network characteristics	Interactive network RIS	Localist grassroots RIS	Globalized dirigiste RIS
Size	Large	Small	Medium (increases with number of hubs)
Density	Low	Overall: Medium Core: High Periphery: Low	Medium (decreases with number of hubs)
Network governance	Multi-level	Region	Region external
Dominant actors	None	Research organizations & larger firms	Large firm or research organization
Relevance of regional interaction	High	High	Low
Relevance of cross-regional interaction	High	Low (depends on size of core)	High
Isolates	Few	High	Few
Fragmentation	Low	Overall: Medium Core: High Periphery: Low	Low / Medium
Network structure	Small-world	Core-periphery	(Multiple) hub-and-spoke
Robustness to node failure	Robust	Robust	Highly vulnerable to hub(s) failure
Degree distribution	Power-law like	Bimodal	Bimodal
Highest betweenness centrality	Organizations (firms) connecting clusters	Leading firms	Public R&D actors or hub firms
Network centralization	Low	Medium	High (depends on number of hubs)

Own illustration

The paper marks a first attempt to close this gap by evaluating evaluated arguments made in RIS research on knowledge sharing and interaction structures. In the theoretical discussion we focused on three ideal-typical types of RIS put forward by Cooke (1998, 2004): the interactive network RIS, the localist grassroots RIS, and the globalised dirigiste RIS. For these we derived a number of network-theoretical expectations concerning their regional knowledge networks. We thereby add to the integration of the two (still) largely unrelated streams of literature on RIS and network research and provide inputs for empirically testable hypotheses in future research. The results are summarised in Table 1.

Given the significance of knowledge relations and R&D related interaction in RIS, we hope to lay the basis for an explicit *network dimension* to the RIS framework. Such will sharpen and enrich existing RIS classifications and enhances the application of analytical and methodological concepts of network analysis within this framework.

The benefits of integrating the network perspective into RIS Research are, however, not limited to scientific issues. For instance, network-related insights can be used as additional input for tailored policy designs that aim to stimulate (regional) collaborative R&D and knowledge exchange. Moreover, SNA may serve as a basis for a more targeted management of interactions and networks in RISs. In the design, execution, and evaluation, a network dimension will valuably complement the existing *Business* and *Governance Innovation Dimensions*.

It is, however, equally important to highlight the benefits of integration for research on inter-organisational networks in Economic Geography. For instance, the present work indicates a certain correspondence of RIS types and distinct network structures. Given that this (so far hypothetical) correspondence will be validated in future research, network-oriented research can be enriched with the substantial insights offered by the RIS literature with respect to organisational and institutional settings.

There are however a number of limitations, of which the most important ones will be addressed in the following. First, we applied the network perspective to the three most ideal-typical RISs of Cooke's RIS concept. It has yet to be shown whether the network perspective will be as insightful when the remaining six RIS types and other RIS concepts as e.g. outlined in Asheim & Isaksen (2002) are considered.

Second, we included common but rather basic network-theoretical concepts in the discussion. Additional insights can surely be obtained by making use of more elaborated and complex network-theoretical concepts in the future. For instance, most of the discussion in the paper took place at the node and network structural level. We almost completely ignored the link (dyad) level.

Third, by and large, we evaluated static characteristics of RIS. That is, with the exception of the interactive network RIS, we didn't elaborated on the emergence and development of these characteristics. These seem to be especially interesting in the case of the interactive network and localist grassroots RIS. In case of the globalized dirigiste RIS, such a debate might be less insightful, since in many instances this RIS is created by an 'external shock' when a multinational enterprise or national agency decides to locate a major facility into a particular region. In contrast, the other two RIS types are valuable subjects for applying an evolutionary perspective and discussing the relevance of path-dependencies and coevolutionary dynamics between networks and RIS structures. For example, small-world properties are more likely to emerge when preferential attachment processes are at work. However, how does this process relate to the formation of a network interactive RIS?

Last but not least, the present paper exclusively puts forward theoretical considerations implying that an empirical validation is still missing. Thus, in addition to further theoretical elaborations, future research should also include a substantial empirical agenda.

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