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Innovator networks and regional knowledge base*

Uwe Cantner† Andreas Meder‡ Anne ter Wal§

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Abstract

This paper concerns the regional innovation system approach. It deals with the characteristics of three regional systems, Northern Hesse, Alpes-Maritime and Jena, and focusses on each regional network of innovators. In this context the importance of the size and homogeneity of a regional pool of knowledge spillovers for those networks is analyzed. We find evidence that an increasing regional knowledge base in combination with an increasing homogeneity of this knowledge base enhances the knowledge flows and the incentives for actors to interact with each other.

JEL classification: O31, P25, Q55

Keywords: cooperation, innovator networks, complementarity of knowledge, interaction structure

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1 Introduction

Drawing back on Schumpeter (1911) many economists nowadays agree on the widely-held view that innovation is crucial for economic success. Many studies in the economics of innovation are concerned with an actor's or an firm's environment for explaining the where and how innovation comes into being. A key role is assigned to an innovative milieu, considered to be both a result as well as an input to innovative activities, in which innovative actors exchange ideas and knowledge, cooperate and often collectively invent and innovate. Thus, the externalities from knowledge production seem to be pivotal for further progress.

Marshall (1920) suggested an externality-driven world of industrial districts, where *"some spirit is in the air"*. Several streams of recent research are based on this idea from the early 20th century. The key rationale in this literature is that knowledge is created and diffused within a bounded space (Giuliani 2005). Knowledge externalities are in the air, available to firms within the spatially bounded industrial district, but inaccessible to those beyond this boundary. This line of reasoning is contrary to the concept of knowledge held by neoclassical economists (Arrow 1962), who regard knowledge as a public good that spreads out without any geographical limits and which is accessible by everyone.

Contrary to this view analyses in the past two decades have shown that innovations are unequally distributed through time and space (Jaffe et al. 1993, Audretsch & Feldman 1996, e.g.). Unequal access to spatially bounded knowledge might play a key explanatory factor here. This proposition has been studied from several points of view. Network theorists have explored the conditions under which information (just like diseases) spreads over a connected graph (Watts & Strogatz 1998, Newman 1999, Schilling & Phelps 2005, e.g.). At the same time, economists have been concentrating on differences in regional development (Sternberg 2000, Fritsch & Mueller 2004) and the importance of a firm's knowledge base for its ability to absorb knowledge from its environment (Cohen & Levinthal 1990, Combs & Ketchen 1999).

With this conception of knowledge in mind this paper builds mainly on the regional economic development tradition. In doing so, we integrate the idea of network theorists that knowledge flows through distinct channels that can be identified and hence can be analyzed quantitatively by graph theory. More specifically, the aim of the paper is twofold. First, we examine how the size of a region's knowledge base affects the extent firms are actively participating in a regional cooperation network. Second, we test how this relationship is affected by the structure of the regional knowledge base and the complementarity of the different knowledge stocks innovative actors hold. In other words, whereas we first assess the influence of geographical proximity on knowledge spillovers, we secondly incorporate the notion of cognitive proximity into our analysis.

Before testing these relationships, we have intensively reconstructed regional knowledge networks and their short-term evolution on the basis of patent data for three regions: Northern Hesse and Jena in Germany and Alpes-Maritimes in France. We can show that the networking activities differ widely between these three regions and that the amount as well as complementarity of the regional knowledge base seems to affect different types of interaction behavior.

We proceed as follows. A brief literature overview and the derivation of appropriate hypotheses in section 2 is followed by the introduction of our methodology and the three regions under consideration in section 3. Section 4 then provides an analysis of the network structures and their development.

After an introduction of the regional pool of knowledge spillovers in section 5, a statistical analysis concerning the role of the regional pool of knowledge spillovers in terms of its size and homogeneity on innovator networks is provided. We close our paper by summarizing our results and pointing to issues to be taken up in future work (section 6).

2 Theoretical background

Recent literature on knowledge creation and networking is mainly built on two basic elements (Cassi & Zirulia 2004): the heterogeneity of the actors involved and the process of collective learning taking place among them. While the latter stresses the interactions between individual actors that lead to the creation of innovations, the former considers the economy as a heterogeneous population of actors, who to a different degree are able and active in creating and diffusing new knowledge (Cassi & Zirulia 2004, p.4). These two dimensions together will help to understand and explain differences among regional innovation systems (RIS) in general and the three sytems under consideration in this paper, namely Kassel-Northern-Hesse, Sophia Antipolis-Alpes-Maritime, and Jena. For this empirical analysis we first want to briefly introduce the bare bones of the RIS concept.

2.1 Concept of Regional Innovation Systems

The general concept of innovation systems draws on pioneering work by Freeman (1987), Lundvall (1992) and Edquist (1997). Meanwhile this basic concept has been interpreted in several dimensions and nowadays it is one main part in the field of innovation research. Edquist defines an innovation system in rather general terms as "all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations." (Edquist 1997, p.14). Following the interpretation of Asheim & Coenen (2005), the main issue of this approach is to explain how innovations occur and not so much how they diffuse and are used with all the consequences on economic development.

The Regional Innovation System (RIS) approach (Cooke 1992) developed from the empirically based acknowledgement that innovation geographically is not equally distributed but rather a bounded phenomenon (Asheim & Isaksen 2002). Various empirical studies describe a sometimes even outstanding regional innovative performance (e.g. Porter 1990, Jaffe et al. 1993). On this basis the identification and understanding of regional resources stimulating the innovative capabilities of regions and the firm/actors located there are a foremost concern of the RIS approach (Asheim & Isaksen 2002). The core idea here is to understand the network or system of actors just as a system built up by regional resources. Close spatial (hereby often implying social) proximity promotes the establishment of those networks which ease the exchange of knowledge and information and thus contribute to collective learning and the subsequent creation of knowledge.

According to Carlsson et al. (2002), a system is made up of components, relationships and attributes. A *component* is an operating unit of a system. That either can be a physical one such as a firm, an actor or a player; or it shows a more intangible nature like institutions in the form of legislative artifacts such as regulatory laws, traditions, and social norms. The systemic nature occurs as these components do not act in isolation, but they interact with each other; hence there exist relationships among components. A *relationship* does not necessarily predict a specific action but it implements a reaction of some or all components to an action by an other component. Hence, each system component depends on the properties and behavior of all other system components. Consequently, a system cannot be divided into several subsystems that are independent of each other (Blanchard & Fabrycky 1990). Both the components and the relationship between them constitute the *whole system*. The *attributes*, as described by Carlsson et al. (2002), define the characteristics of a system. Edquist (2001) uses the term *boundaries* in the same sense. Both are features crucial for understanding the system and related to the dimension a system is analyzed.

Interested in the systemic aspect of innovative activities, we look at the core of the RIS approach suggesting that the regional innovative performance is positively dependent on the systemness of the innovative activities in that region (e.g. Owen-Smith & Powell 2004, Boschma & ter Wal 2005). Hence, as system components we consider innovative actors among which are firms, research institutes, individuals, etc.[1] The relationships among these components are various ways of knowledge exchange or transfer. The attributes of the systems are the knowledge bases of the actors and a system's boundaries are regionally determined.

In order to understand the interaction in that type of networks a discussion of the heterogeneity of actors, their collective learning and their proximity in the spatial and technological

[1]Since we have no information about the regional institutional frame, we have to concentrate on actors as the only available type of regional components yet.

dimension is required. We start with the concept of actors' heterogeneity.

2.2 Heterogeneity

The observed heterogeneity of firms in an economy can be explained by the ontogenetic approach of the "resource-based view of the firm" (RBV). The RBV, bearing heavily on Penrose (1959), considers the individual firm as a collection of productive resources (Barney et al. 2001). Here resources are defined as "those assets that are tied semi-permanently to the firm" (Wernerfelt 1984, p. 173). Hence, they are sticky. Resources of this type comprise fully appropriable assets, like special or unique equipment or patents, or more intangible ones, such as human capital, specific capabilities or firm routines (Silverman 1999, p.1110). The range of intangible assets includes also knowledge of certain technologies and scientific principles but also of specific markets or customer groups, decision-making techniques and management systems (Mowery et al. 1998, p.508). Such resources are called dynamic if they evolve over time and constitute among other things "the learning capacity of a firm" (Lockett 2001, p.725). The process by which resources in this sense are built up or accumulated is a historical and path-dependent one and partly individualistic or idiosyncratic. The observed heterogeneity of actors or firms in terms of their knowledge at a certain period t can then be seen as the result of such dynamics up to t.

This idiosyncracy or path-dependency in the process of building up knowledge by learning and generating new ideas is rather selective in the sense of the range of fields or areas of knowledge addressed. It can be interpreted as a result of actors' way to cope with the uncertainty inherent to innovative activities (Dosi 1988). This behavior is characterized by trail and error (Loasby 1999, Boschma 2005) where firms and economic actors in general develop certain routines to cope with this uncertainty and integrate them into their search and creative activities (Nelson & Winter 1982). Knowledge stocks built up in that way are often idiosyncratic, sticky, and hard to imitate. In the RBV those stocks just meet the criteria of resources. And according to Combs & Ketchen (1999) and Lockett (2001) those resources are crucial for the competitive advantage of a firm and determine her performance (Barney 1991).

2.3 Collective learning

To overcome the uncertainties characterizing innovative activities actors develop certain routines to build up appropriate knowledge and competencies. Among those an important routine is learning. Besides learning by own experience another routine is to learn from others and to cooperate in research and development. By this an actor attempts to internalize external intangible knowledge and to exchange it against own knowledge. Hereby, external knowledge affects the internal learning processes of a firm. This exchange of knowledge resources in the sense of the RBV is based on social interaction, can be considered a process of collective learning, and may even lead to collective invention and innovation (Allen 1983).

Collective learning is based on the transfer or the exchange and therefore on the flow of knowledge and information. Flows of external knowledge are discussed under the heading of "R&D spillovers"(Arrow 1962). In his review of the spillover literature Griliches (1992) concludes that "studies generally seem to confirm the presence and influence of R&D spillovers" (Dumont & Meeusen 2000, p.3). He suggests the distinction between "embodied spillovers", like equipment, goods and services, and "disembodied" ones. For embodied spillovers the external effects are often analyzed by commodity flows such as represented by input-output-tables that show the importance of buyer-supplier relationships for learning processes (see for example Coe & Helpman (1995), Debresson (1999)). For disembodied spillovers this measurement device is not available. Griliches defines them as *" ... ideas borrowed by research teams of industry i from the research results of industry j. It is not clear that this kind of borrowing is particularly related to input purchase flows"* (Griliches 1992, p.36). A major problem of empirical research is to identify and possibly quantify the knowledge flows in such cases. The concept of proximity of actors may help to find an approximate solution to this issue.

As mentioned above, a each firm can be considered unique in terms of the set of sticky resources. This "stickiness" is due to the inherent nature of knowledge that makes it different from traditional inputs (Dosi 1988). Knowledge is considered partly as a latent public (Nelson 1990) and partly as tacit. In the former case it will not diffuse immediately from a one firm to another, and in the latter case this may even be impossible. Here, networking is a way for a independent firm to get access to the sticky as well as to the tacit knowledge of another firm (Mowery et al. 1998). For networking to be effective in inducing spillovers between actors certain conditions of proximity have to be satisfied (Boschma 2005). Two proximity concepts are of importance here, spatial proximity and technological proximity.

2.4 Spatial proximity

An important dimension analyzed in order to explain intended technological spillovers or the phenomenon of research cooperation is the spatial proximity between the actors. The idea is that only actors that know and trust each other will exchange and transfer knowledge. A condition for that is spatial (and social) proximity. This issue is taken up by a couple of theories dealing with the geographical concentration of firms and the resulting impact on economic success of regions or single firms. A first group of authors (e.g. Holbrook & Wolfe 2000, Brenner 2002, Giuliani 2005) focus on the concept of a "cluster", describing the horizontal concentration of an industry in a certain region and the resulting Marshallian externalities.

Another group of researchers (e.g. Asheim & Isaksen 2002, Doloreux 2002, Asheim et al.

2003, Fritsch & Franke 2004, Cantner & Graf 2006) concentrates on "Regional Innovation Systems". These systems are not restricted to a single industry. In this sense there are not only Marshallian externalities but also so called Jacobian externalities (Jacobs 1969) at work which address the knowledge flows among actors of different industries. In addition to that RIS comprise all actors in a certain region that are involved in the process of knowledge creation and innovation. Besides the "traditional" knowledge creating actors like firms and private research institute, they include non-market actors like public research institutes (Dahlstrand 1999, Buesa et al. 2004) as well as public policy makers that play a coordinating role in the processes of knowledge creation and innovation (Dumont & Meeusen 2000, Fritsch & Franke 2004).

How is knowledge transfer by networking related to the concentration of innovative activities in space? Research and innovation activities are not equally distributed in space. In some regions more firms, research institutes or individual actors are engaged in innovating than in other regions. In other words the aggregate regional knowledge base differs across regions and consequently also the pool of knowledge spillovers. The knowledge pool of a region is built up by the actors involved and their specific knowledge stocks. The more knowledge generating actors a region shows and the higher their respective knowledge stocks the larger the pool of external knowledge each actor may draw from. Hence, we expect that the number of actors and their individual innovation-related activities positively influence the extent to which networking activities and thus cooperative innovation takes place in a region:

> Hypothesis 1: The higher the number of actors (firms, research institutes or even private persons) in a region pursuing innovative activities, the larger is the pool of knowledge spillovers and the more firms tend to actively use the external knowledge pool of the region by means of regional knowledge networks.

2.5 Technological proximity

Beside the geographical dimension of proximity, there are other dimensions showing up in recent literature on knowledge spillovers and cooperation networks (Boschma 2005). Of special interest for our study is technological or cognitive proximity. The idea here is that for knowledge flows between actors to be effective the recipient firm has to be able to understand the sender firm's knowledge. The respective capabilities to understand external knowledge are directly related to the firm's own knowledge base seen as a bundle of resources in the RBV sense. By the same degree by which firms differ in those resources they do differ by their abilities to understand and use external knowledge (Boschma 2005). In other words, actors show different absorptive capacities (Cohen & Levinthal 1990).

In this sense the pool of regional knowledge spillovers has an individual value for each of the firms acting in this region. This value depends on the degree of complementarity between the firms' resources (Nooteboom 1999) and on the respective absorptive capacities. The higher this value the more a firm will be able and willing to draw on external knowledge. This argument can be extended to the regional level as formulated in the following hypothesis:

> Hypothesis 2: The higher the complementary between the knowledge bases of firm within a region are, the more those firms will have network linkages within the region in order to integrate external knowledge into their knowledge stocks.

3 Methodology and data base

The two hypotheses presented in the previous section will be tested on the basis of three regions: Northern Hesse and Jena in Germany and Alpes-Maritimes in France. In order to do so we investigate the respective innovator networks. A region's innovator network is built up by the interaction between several actors within a region as well as between actors inside and actors outside the region. Innovation here is meant in the sense of transferring and exchanging knowledge and information. For these networks we test whether certain measures for the intensity of knowledge flows are dependent on measures characterizing the regional knowledge base. The next session explains how the region's innovator network have been reconstructed and introduces briefly the three regions to be analyzed.

3.1 Methodology

For constructing the regional innovator networks as well as for characterizing the respective regional knowledge base we use patent data. Sources are the "Deutsche Patentblatt" for both German regions and data from the European Patent Office for the French region. The former source includes all patents applied for at the German patent office and at the European patent office for Germany between 1998 and 2003. For the same period we use EPO patents for the French region of Alpes-Maritimes.[2]

Boundaries and Interaction Structures

Using these data we construct networks of innovators where the nodes are the innovators and the ties between the nodes represent the interaction between innovators. The innovators

[2] National French patents, usually more numerous than EPO patents, are not included. Hence, the total number of patents is inherently smaller for the French region.

in those networks are the patent applicants. Our task has been to identify the innovators pertaining to a certain region and the modes of interaction between those innovators. For this we rely on the following information given by a patent: names and addresses of applicants, names and addresses of the inventors, year of application. These data are used as follows:

(1) First, we assign each patent to a certain region. For that, on a patent document there are two fields for addresses which can be used, the address(es) of the applicant(s), the actor(s) in our networks, and the address(es) of the inventor(s). Assignment problems occur if both addresses differ which might be the case if the inventors' R&D activities took place in a branch located in region i but the patent is filed for by the headquarter located in region j. There exists a convention in recent literature saying that using the inventor's address causes minor disadvantages (e.g. Sorenson et al. 2006, Cantner & Graf 2006). Greif and Schmiedl argue that the "inventor domicil concept reflects the real location of R&D more conveniently" (Greif & Schmiedl 2002, p.6). Based on this convention we assign a patent to one of our regions if at least one of the inventors stated is located in that region.

(2) Using the names of the applicants and of the inventors of all patents belonging to a certain region in period t, we construct a network of innovators (i.e. applicants) for that period t. The nodes of the network, in the following called "actors", are the patent applicants. An actors can be a firm as well as a research institute or even a private assignee. Using patent data there are two possible ways of relationships between the actors to come up:[3]

(a) First, a classical "research cooperation" might result in a co-patent application, where the participating firms or institutes are all listed as patent applicants. In this kind of relationship direct bi-lateral knowledge flows are established between all partners. All the participating firms or institutions are assumed to be able to internalize a certain degree of the tacit and sticky knowledge from their cooperation partners.

(b) The mobility of researchers is a second form of knowledge transfer between two firms. In patent data "labor mobility" is retraced if one inventor is named on the patents of different not co-applying applicants. In that case we assume that this inventor worked for both applicants. Here the knowledge flow is not bi-lateral, because only the inventor's new company can benefit from the knowledge base of the former researchers' employer. However, not all cases of "multiple-applicant inventorship" can be interpreted as a result of labor mobility. There exists an alternative explanation of an inventor occurring at patents of different applicants, which we label "hidden cooperation": Many cooperating firms decide to divide the patents that result from their cooperation among themselves (Hagedoorn 2002). Thus, only one of the cooperating firms is named as applicant on the patent resulting from an cooperation. The inventors, however, belonging to either one of the two cooperating companies, occur on all patents. We

[3]For a detailed explanation of using patent data for social network analysis, see Cantner & Graf (2006).

label this case labor mobility too, since the data we use do not allow distinguishing these two cases.

For constructing the innovator network both types of connections, cooperation and labor mobility, have been identified separately. The following analysis of the network structure, however, will be performed on the basis of both types of knowledge transfer together. We are aware of the problems using this methodology. The weakness not to know whether in the observed connection the knowledge flow is two-sided or not must be accepted at this time.[4]

Finally, we achieve at a network consisting of regional actors and their external partners as described in the RIS approach. For these networks we observe their development between 1998 and 2003. As the regional network is too sparse in the case of one-year time periods, we used four three-year periods with an overlapping year between the periods. These four subperiods (1998-2000, 1999-2001, 2000-2002, 2001-2003) allow us to characterize the development of the three regional knowledge networks and to draw conclusions on the regional knowledge base as an influential factor.

Knowledge flows and small world properties

We focus on a specific feature of innovator networks, their function as a knowledge transfer channel (Sorenson 2003). Drawing on sociological work related to knowledge networks (Granovetter 1973, Burt 1992) economic research such as Newman (1999), Kogut & Walker (2001), Cowan et al. (2004*a*,*b*) and Fleming et al. (2005) analyze innovation networks and knowledge diffusion. Empirical as well as simulation analyses suggest that a certain network structure fosters the knowledge flow within the network, the "Small-World" (SW) property based on Milgram (1967) and formalized by Watts & Strogatz (1998).

In order to identify the SW property of a network one computes the cluster coefficient and the mean-shortest-path length. The former represents the number of the direct neighborhoods an actor shows, the latter indicates the average distance an actor has to all other actors engaged in the network. SWs show a high clustering coefficient and a low average path length, and by this sustain the knowledge flow between the network actors (Watts & Strogatz 1998). The better a network fulfills the requirements of a SW the better the internal flow of knowledge.

To apply this formal concept of an SW in an empirical analysis, however, one regularly faces considerable problems. First, such kind of analysis requires information of all actors involved in a network. A representative sample of actors obviously does not satisfy this condition. A network constructed on the basis of patent data information (co-applications, labor-mobility), however, can be considered complete in this sense - it connects all actors successfully engaged

[4]But we are looking forward to cope with this problem in future work.

in inventive activities and willing to patent. Unfortunately, in most cases the latter do not fulfill a second criterion, the full connectivity of the network. In order to calculate the average path length, all actors of the network have to be connected with each other, at least in an indirect way. This is just what full connectivity means, but what one rarely observes in empirical data. Therefore, empirical studies often use the largest connected component of a network to test for SW characteristics (Sorenson & Fleming 2004, Fleming et al. 2005). Here the largest component is assumed to represent the whole network; this, however, is only acceptable when it shows a sufficiently high share of the whole network.[5]

3.2 The three regions

The three regions to be analyzed are characterized as follows: The first region, "Northern Hesse", contains six "Landkreise" and its economic structure shows a strong reliance on established and more traditional industrial activities. The economic development of Northern Hesse is shaped by the descent of heavy industries like railway engineering and defense industry in the late 80's of the 20th century. Nowadays regional politicians and business development agencies are trying to support the emergence of clusters in different technologies. The MOWiN.net for example is a public financed network of regional business agencies concentrating on the logistics sector.

The second region we consider is Alpes-Maritimes at the French Côte d'Azur. It is located between the Mediterranean Sea and the Alpes with Nice as the largest city. Beside tourism the economic performance is mainly influenced by the successful science park Sophia-Antipolis, located southwest of Nice. Founded in the early 80's of the last century, it houses primarily companies in the fields of computing, electronics, pharmacology and biotechnology. It was created as a public financed project in vacant space, in a region with no university or industrial tradition. At its initiation, this project was characterized by the absence of different factors influencing the innovative success of regions (Longhi 1999). Nowadays, over 1300 firms are located within this park and global players like Hewlett Packard or Phillips Electronics have branch offices there.

The third region under investigation contains the city of Jena, the neighboring "Saale-Holzland-Kreis" and two postal code areas next to Jena, Apolda and Mellingen. This region's industry structure is clearly dominated by the city of Jena strong in several knowledge intensive industries. The economic structure of Jena has a long tradition and today is still affected by the existence of the "Kombinat Carl-Zeiss" in times of former GDR. Jenoptik, Zeiss and Schott are the main successors of this Kombinat. Besides these other optic firms as well as firms from

[5]As we will show later on, two of our three regional networks are far from satisfying this condition.

pharamaceutics, IT and biotech are located in Jena.

4 Analysis

4.1 Network actors

Components of a innovator network are actors and institutions. Hence we have no information about the institutional endowment of the three regions, we concentrate on the actors and their characteristics. Among network actors firms and individual actors hold the largest share followed by public research institutes which serve a specific role within the network. Their major function is the generation and accumulation of knowledge, its diffusion into the regional knowledge stock, and the education of highly skilled workforce capable of performing high-level industrial R&D (Fritsch & Schwirten 1999). Therefore, public research institutes provide a highly valuable input to the regional innovation system (Graf & Henning 2006). Furthermore, we distinguish network actors which are located within the region (internal actors) and those which are external to the region but hold connections to internal actors.

Northern Hesse

For the network of innovators in Northern Hesse table 1 contains information about the actors involved. The network consists of 212 actors in the period 1998-2000. Thereof, 105 (49.5%) have been identified as actors located within the region (internal actors).

Table 1: Network Actors and their characteristics in Northern Hesse

Years	1998-2000	1999-2001	2000-2002	2001-2003
Number of actors	212	224	185	174
Development of actors		5.7%	-17.4%	-5.9%
Number of internal actors	105	107	83	85
Share of internal actors	49.5%	47.8%	44.9%	48.9%
Number of public research centers	8	9	8	8
Share of public research centers	3.8%	4.0%	4.3%	4.6%

Over time the number of actors in Northern Hesse decreases constantly (except for 1999-2001). In the final period 2001-2003 we observe 174 actors. The share of internal actors is not much affected by this development (except for 2000-2002) and stays consistently below 50%.

Looking at public research institutes the network of innovators in Northern Hesse shows 8 institutes in each period (except 9 institutes in 1999-2001). As the total number of actors decreases over time, the share of public research institutes slightly increases from 3.8% in 1998-2000 to 4.6% in 2001-2003.

Alpes-Maritime

Table 2 shows that in 1998-2000 the network of innovators comprises 318 actors of which 180 (56.6%) are identified as internal actors. Contrary to the development in Northern Hesse, the number of actors in this regional network is increasing over time, with a decreasing share of internal actors. This is probably due to the increasing number of branch offices which led to an increasing number of patent applications by applicants located outside the region.

Table 2: Network Actors and their Characteristics in Alpes-Maritime

Years	1998-2000	1999-2001	2000-2002	2001-2003
Number of actors	318	324	323	358
Development of actors		1.9%	-0.3%	10.8%
Number of internal actors	180	181	169	183
Share of internal actors	56.6%	55.9%	52.3%	51.1%
Number of public research centers	8	7	8	8
Share of public research centers	2.5%	2.2%	2.5%	2.2%

The absolute number of public research institutes is similar to those of Northern Hesse, but as the total number of actors increases the share of public research institutes declines from 2.5% in 1998-2001 to 2.2% 2001-2003.

Jena

The innovator network of Jena in 1998-2001 comprises 254 actors, whereof 123 (48.4%) are identified as internal actors (see table 3). After an increase in 1999-2001 (277), the number of actors remains considerably stable in the in the following two periods (257, 249). The number of internal actors follows this trend, so that their share is nearly constant over time and slightly below 50%.

Actors belonging to public research institutes are more numerous in the Jena network compared to the two other networks. We identify 18 institutes in 1998-2001, increasing over time to 25 actors in 2001-2003. Their share increases from 7.1% to 10%.

Table 3: Network Actors and their Characteristics in Jena

Years	1998-2000	1999-2001	2000-2002	2001-2003
Number of actors	254	277	257	249
Development of actors		9.1%	-7.2%	-3.1%
Number of internal actors	123	135	124	120
Share of internal actors	48.4%	48.7%	48.2%	48.2%
Number of public research centers	18	22	24	25
Share of public research centers	7.1%	7.9%	9.3%	10.0%

4.2 Connections and Densities

Having discussed the characteristics of the network actors, the structure of each of the three regional innovator networks will be introduced next. The interactions involved are the basis of certain network structures to be investigated in further steps. This systemness or systemic character of regional innovative activities mainly shows up in the number and the intensities of interactions and is less dependent on the number of innovative actors.

Our analysis is based on the two types of interaction introduced above, the more formal research cooperations and the interaction by "labor mobility". It is important to recognize here that those connections indicate successful interactions since they led at least to a patent. Obviously more modes of interaction are expected to be relevant. Taken these two types of interaction together leads to a network which can be viewed as "a lower barrier of actual relationships"(Cantner & Graf 2006, p.469).

Table 4 contains information on the number of relationships of both types for each network. Panel A refers to Northern Hesse, Panel B to Alpes-Maritime, and Panel C to Jena. The first row in each panel shows the number of research cooperations. For Northern Hesse this number is decreasing over time from 30 to 18. This type of interaction starts in Alpes-Maritime with 36 research cooperations in 1998-2000, increases to 41 and 45 and then declines to 36. Compared to these two regions Jena shows a much higher number of research cooperations. Starting with a number of 161 research cooperations in 1998-2000, which is more than twice the amount of both other regions together. This number constantly decreases to 152 research cooperations in the last period. The number of research cooperations in both German networks are decreasing over time and the formal interactions are much higher in Jena than in the other two networks.

The second row of each panel provides information about the number of labor mobility ties. For Northern Hesse in 1998-2000 we find 52 connections and 56 in 1999-2001. After that there is a sharp decline to 34 and to 18 in 2001-2003. A similar development is to be observed for Alpes-Maritime. Here the number of labor mobility ties decreases from 114 in 1998-2000 to

Table 4: Relationships and network densities in regional knowledge networks

Panel A: Northern Hesse

Years	1998-2000	1999-2001	2000-2002	2001-2003
No. of research cooperation ties	30	28	20	18
No. of labor mobility ties	52	56	34	13
Number of connections	125	134	145	66
Number of connections (dichotomized)	47	50	32	27
Density	0.0021	0.0020	0.0019	0.0018

Panel B: Alpes-Maritime

Years	1998-2000	1999-2001	2000-2002	2001-2003
No. of research cooperation ties	36	41	45	36
No. of labor mobility ties	114	108	104	86
Number of connections	178	178	189	141
Number of connections (dichotomized)	143	144	155	109
Density	0.0028	0.0028	0.0030	0.0017

Panel C: Jena

Years	1998-2000	1999-2001	2000-2002	2001-2003
No. of research cooperation ties	161	158	153	152
No. of labor mobility ties	838	856	696	612
Number of connections	1590	1558	1422	1336
Number of connections (dichotomized)	915	933	862	757
Density	0.0285	0.0244	0.0262	0.0245

86 in 2001-2003. As for research cooperations the number of labor mobility ties in Jena is much higher than in the other two networks. However, their development is similar to the one of Northern Hesse and Alpes-Maritime. In 1998-2001 we find 838 connections. This number decreases over time to 612 relations in 2001-2003.

Combining both kinds of connectivity makes up the regional innovator network. The respective aggregated numbers are found in the third row for each panel in table 4. They reflect the total number of connections in the network. Dichotomizing the observed ties provides information on the number of actors connected to each other. With respect to get information on the systemness of the regional innovative activities the dichotomized measure is to be preferred. Not surprisingly the innovator network in Jena (915 in the first period) contains the most connections followed by Alpes-Maritime (143) and Northern Hesse (47). Comparing the first and the last period the number of connections decreases in all three networks.

The last indicator provided in table 4, the network density, completes the description of the three innovator networks and their development. The density of a network is computed by the ratio of all ties observed over the number of all possible ties for the dichotomized network. Hence this indicator relates number of connections and number of network actors.

While the three innovator networks are rather similar in their number of actors, with respect to the number of connections clear differences show up. Due to the much higher number of connections in Jena, the network there shows a much higher density (about tenfold) than the other two networks. Over time we observe a slight decrease of the network density in all three regions. For Northern Hesse it is the drastic decline in the number of relations (-43%) combined with a less pronounced decline in the number of actors (-18%) that provides for a slight decrease of the density from 0.0021 in 1999-2001 to 0.0018 in 2001-2003. Compared to Northern Hesse the innovator network of Alpes-Maritime shows a higher density in first period. Due to an increase in the number of actors (12%) and a decline in the number of connections (-24%) the density declines in 2001-2003 to 0.0017, a level close to the one in Northern Hesse. For Jena the number of connections (-17%) as well as the number of actors (-5%) decreases - the latter much less. However, density stays at the same level (0.0285 in 1998-2000 to 0.0245 in 2001-2003). Hence, in Jena rather less connected actors seem to leave the network over time.

4.3 Fragmentation

Having shown differences in the density of the three networks, in this subsection we discuss the structure of networks as a whole and their development. Table 5 includes in three panels information about the structural characteristics of each innovator network and their development over time.

Table 5: Fragmentation and Components in regional knowledge networks

Panel A: Northern Hesse

Years	1998-2000	1999-2001	2000-2002	2001-2003
Freeman Degree	0.769	0.855	0.585	0.406
Fragmentation index	0.999	0.999	0.999	0.999
Number of isolates	121	136	116	114
Share of isolates	57.08%	60.71%	62.70%	65.52%
Number of components	5	6	4	4
Actors in largest component	12	9	4	3
Share of largest component	5.7%	4.0%	2.2%	1.7%

Panel B: Alpes-Maritime

Years	1998-2000	1999-2001	2000-2002	2001-2003
Freeman Degree	1.563	1.557	1.505	0.594
Fragmentation index	0.994	0.995	0.989	0.991
Number of isolates	153	152	154	219
Share of isolates	48.11%	46.91%	47.68%	61.17%
Number of components	23	22	16	13
Actors in largest component	14	13	28	33
Share of largest component	4.4%	4.0%	8.7%	9.2%

Panel C: Jena

Years	1998-2000	1999-2001	2000-2002	2001-2003
Freeman Degree	7.205	6.736	6.708	6.08
Fragmentation index	0.905	0.882	0.921	0.936
Number of isolates	68	66	69	62
Share of isolates	27.76%	24.91%	28.28%	25.62%
Number of components	2	3	6	7
Actors in largest component	112	114	87	78
Share of largest component	44.1%	43.0%	35.7%	32.2%

The knowledge flow within a network depends on the connectivity of all actors involved. The pure number of connections is misleading in this respect as it is not related to the number of potential connections which are possible within an innovation network. Thus, the Freeman degree[6] reflecting the centrality of each vertex is introduced here as a first indicator of the overall knowledge flow within a network. This degree of centrality measures the overall network activity of individual actors. Concerning our sample the first rows for each panel in table 5 show the Freeman's degree for each subperiod. We observe (i) that there exist clear differences between the three regions and (ii) that the values decline in all three regions over time. So one can conclude for the innovator network in Jena the entire network is more focused around a few central nodes than in the two other innovator networks. Graf & Henning (2006) show the increasing importance of public research institutes for the regional network of Jena.

As mentioned before nearly no empirical innovator network will be fully connected. An aggregate indicator for the connectedness of a network is the fragmentation index. It states the share of pairs of actors which are unreachable from each other in all pairs of actors; in the context of our innovator networks this is interpreted as the share of pairs of actors between which no know-how flow takes place. This index ranges from 0 to 1 where 1 indicates a fully fragmented network. The second rows in table 5 show the fragmentation indices for all networks and their development over time. In Northern Hesse the index is close to 1 which means that for this innovator network the share of unconnected actors is considerably high. The network in Alpes-Maritime has a lower fragmentation index which is slightly decreasing over time; hence, the connectedness of actors increases of time. The innovator network in Jena shows the lowest values. They are slightly increasing over time reflecting the declining absolute number of connection mentioned above.

The fragmentation of a network is caused by isolated actors and by actors which are connected in components. Two actors are (not) member of the same component if there is (no) a direct or indirect path connecting them (Borgatti et al. 2002). The occurrence of several components in a network indicates that there are networking activities where the knowledge flows are bounded within different cliques. In innovator networks these cliques are often technology driven group formations.

Rows 5 to 7 of each panel in table 5 display the number of components, the number of actors in and the share of the largest component.[7] In our sample the innovator network in Northern Hesse consists of 4 (3rd and 4th period) to 6 (2nd period) components. In Alpes-Maritime this number is much higher. Here starting with 23 components in the 1st period, the number is decreasing to 13 in the last period. Contrary to this development the number of components

[6]"The number of vertices adjacent to a given vertex in a symmetric graph is the degree of that vertex" (Borgatti et al. 2002)

[7]In our analysis a component has to consist of at least three actors.

in Jena is increasing but on a much lower level. In the first period there are only 2 components identified. This number increases over time to 7 components in the last period.

In Northern Hesse the largest component comprises 12 actors (5.7%) in the first period which is rather low. Furthermore, the share of the largest component decreases over time to 1.7% in the last period. The largest component in Alpes-Maritime comprises more actors (13-33) and its share is increasing over time from 4.4% to 9.2%. In Jena the largest component comprises in the 1st period 112 von 254 actors which are 44.1%; this share decreases to about 32% in the fourth period.

The third and fourth rows in table 5 show the number of isolates and their shares. The regional innovator networks in Northern Hesse and Alpes-Maritime consist of much more isolated actors which are no member of any component. In Northern Hesse the number of isolates is fluctuating around 120 actors which means that around 60% of all actors are not connected either through co-applications or scientist mobility. The number of isolates in Alpes-Maritime is increasing in the last period from around 150 in the first three periods to 219 in the last one. Their share is nearly constant in the first three periods (around 50%) and jumps up in the last period to 61.17% which is highly comparable to the value of the first observed network of Northern Hesse. The number of isolated actors in Jena is much smaller. Their number is nearly constant over time and fluctuates between 69 (3rd period) and 62 (4th period). Their share in all innovative actors is about 25% throughout.

Based on the characteristics of the three regions' innovator networks with respect to the number of components (smaller for Jena and Northern Hesse; larger for Alpes-Maritime) and the share of isolated actors (smaller for Jena; larger for Northern Hesse and Alpes-Maritime) one can conclude that knowledge flows most easily in the Jena network. The lowest rate of diffusion could be expected in the regional network for Northern Hesse. Here, a high share of actors is isolated which means that they are not participating in regional collective learning. The regional network for Alpes-Maritime is somewhere in between. Interactive learning takes place, indicated by a lower share of isolated actor (except of the last period) but these collective learning activities are concentrated in independent components rather than in one larger research community (highest number of components; low share of largest component). Thus, one could conclude that in this regional network knowledge is shared by independent groups of researcher which might be due to specifities of the regional technological endowment.

4.4 The Small World of Jena

The diffusion of knowledge, however, is not only dependent on the number of interactions but, as already mentioned above, on the network structure. One way to analyze the regional network structure according to its knowledge flow characteristics is the small-world concept introduced by Watts & Strogatz (1998). In order to test for SW properties of a network the largest component has to represent a sufficient share of the whole network. For Northern Hesse and Alpes-Maritime the largest component is not representative for the complete network so that we cannot test for SW characteristics. For Jena, however, the share of the largest component is always about 1/3 so that it can be used to test for SW characteristics. Thus, the innovator network of Jena will be analyzed in this subsection according its small-world-properties.

Small-world networks are identified as a class of random graphs by Watts & Strogatz (1998). They noted that graphs could be classified according to their clustering coefficient and their mean-shortest path length. Many random graphs exhibit a small mean-shortest path[8]. Furthermore, they also usually have a small clustering coefficient[9]. Contrary to random networks, many real-world networks have a small shortest path but also a clustering coefficient significantly higher than expected by random chance (Baum et al. 2003). Watts & Strogatz (1998) propose a simple model of random graphs with (i) a small average shortest path and (ii) a large clustering coefficient. The crossover in the Watts-Strogatz model between a "large world" (such as a lattice) and a small-world has been described in several studies (e.g. Baum et al. 2003, Cowan & Jonard 2004, Fleming et al. 2005). The most prominent hypothesis regarding the importance of the network structure is that small-world networks should enhance the innovative creativity (e.g. Watts 1999, Baum et al. 2003, Fleming et al. 2005). According to Watts & Strogatz (1998) the following network characteristics have to be required to analyze small-world properties of a network:

$$n \gg k \gg ln(n) \gg 1$$

where n is the number of connections within a network, k the number of actors. These requirements lead to a sparse but connected ($k \gg ln(n)$) network. According to the values shown in the first two rows of table 6, these requirements are fulfilled for the largest components of the Jena network over all four periods.

Following Watts & Strogatz (1998) a small-world network lies between a regular (long path length and high clustering coefficient values) and a random network (short path length and low clustering coefficient values). Thus, a network which possess small world characteristics has to have an average path length which is comparable to a random network of the same size and density characteristics but the cluster coefficient of the real network has to be much higher indicating that this network is more regular than the random network.

[8]The mean-shortest path is a global property and measure the averages steps between all actors of a network. Thus, all actors have to be connected with each other. It measures the social distance between any two inventors as the minimum number of collaborative links between them (Fleming et al. 2005).

[9]Following Watts & Strogatz (1998), the clustering coefficient indicates the the cliquishness of a typical neighborhood and, thus, it is a local property. It is an indicator for frequent local interactions.

To test for this, the average path length and cluster coefficient values for the Jena networks and for corresponding random networks are presented in table 6. Actors of the Jena network are connected over longer distances on average in comparison to the random network. The differences, however, (2.844 in comparison to 2.041 in the first period) is not that large. Thus we conclude that the observed networks do have relatively short paths. What this implies is that knowledge flows relatively rapidly within component, and the diffusion of distant knowledge, through successive rounds of innovation, can be an active feature of the network. While the average path lengths are comparable between regional and random network, the cluster coefficients are obviously different. For the first period the coefficient value of the regional network (0.775) is over six times higher than the value of the random network (0.124). This discrepancy declines over time which is due to an increase of the networks density and, thus, to an increase of the cluster coefficient values of the random networks whereas the cluster coefficient of the regional networks is nearly constant over time. Based on these results one can conclude that the network of Jena shows small-world characteristics for all four periods.

Table 6: Small World properties of Jena

	1998-2000	1999-2001	2000-2002	2001-2003
Actors in largest component	112	114	87	78
Number of ties	284	264	228	196
Density	0.123	0.108	0.161	0.183
	Network properties of Jena			
Average path length	2.844	3.267	2.767	3.015
Cluster coefficient	0.775	0.812	0.773	0.737
	Comparable random network			
Average path length	2.041	2.125	1.941	1.886
Cluster coefficient	0.124	0.114	0.174	0.202

Thus, referring to Watts (1999), Baum et al. (2003), Fleming et al. (2005) the structure of the Jena network should enhance the innovative capabilities of its actors which is, however, not in the focus of this work. In fact, we are interested in determinants influencing the cooperative innovation activities of all three regions under consideration. Therefore, the regional cooperativeness and, thus, the regional networks are represented in the following section by variables which do not require a complete network like the share of isolated actor.

5 Regional knowledge pools and cooperative innovation

Having discussed the structures of each region's network and their development we now want to turn to the two hypotheses suggested. In principle they claim the network structure depends on the pool of knowledge available within a region (Asheim & Coenen 2005). More specifically we are interested in the impact the pool of regional knowledge spillovers (in the following knowledge pool) and its structure (in terms of homogeneity) have on the region's cooperative innovation observed. Although the working mechanism relating the regional knowledge base to the region's innovator network is explained by theoretical concepts, empirical evidence on this relation is rather scarce. This is due to the difficulties of measuring a regional pool of knowledge and the respective spillovers. In the following we attempt to quantify and structure the knowledge pools of our three regions and relate this to the hypotheses suggested. For this we first discuss the regional knowledge base, its homogeneity and development over time.

5.1 Regional knowledge pools

Size of the knowledge pool

As this study is based on patent data we use the number of patent applications within a certain period as a rather rough indicator for such a pool. The number of patents that have been filed for over a longer time span might be much more adequate as an indicator, but, yet, our sample comprises only information of a 6-year time span. The knowledge pools are indicated through patent applications in the respective period. These information are displayed in the 1st rows of each panel in table 7.

For hypothesis 1 to which the knowledge pool in Northern Hesse has to be the smaller than than the one of Alpes-Maritime, while Jena has to have the largest knowledge pool. For the first period under consideration we, however, find Northern Hesse (590) has a larger knowledge pool than Alpes-Maritime (360). The pool of Jena (730) is the largest in this subperiod.

For the following periods we found for all three networks that the interaction intensity in terms of numbers of connections and in terms of densities is declining over time. Hence, one should expect the same development to hold for the respective knowledge pools. Here, however, a development different among the regions is observable. Whereas the knowledge pool of Northern Hesse knowledge pool is constantly declining, as expected, the knowledge pool of Alpes-Maritime is increasing over time. Furthermore, the knowledge pool in Jena is increasing too.

Complementarity of the knowledge pool

In order to test for hypothesis 2 we have to specify the notion of complementarity. This term is used to indicate the average reciprocal understanding between two member of an innovation network. Therefore, the diversity of the regional knowledge base is taken into account which means that the amount of knowledge will later on be separated among a technological space. The understanding within a technology is taken for granted, whereas we assume that there is no understanding between different technologies. This assumption allows us to discuss complementarity of the regional knowledge base in terms of its homogeneity. This procedure limits,

Table 7: Pool of regional knowledge spillovers and its complementarity

Panel A: Northern Hesse

Years	1. period 1998-2000	2. period 1999-2001	3. period 2000-2002	4. period 2001-2003
no. of patents	590	574	463	440
no of technological fields	38	37	36	36
top 5 tech. fields	F42	F42	F42	F42
	F20	F20	F20	F21
	F22	F22	F22	F17
	F25	F21	F21	F22
	F27	F25	F17	F20
share of top 5 techn. fields	50.51%	54.18%	52.70%	52.73%
Herfindahl Index	0.068	0.068	0.069	0.063

Panel B: Alpes-Maritime

Years	1. period 1998-2000	2. period 1999-2001	3. period 2000-2002	4. period 2001-2003
no. of patents	356	389	460	662
no of technological fields	32	33	35	36
top 5 tech. fields	F35	F35	F35	F35
	F28	F28	F28	F28
	F13	F13	F13	F13
	F10	F37	F37	F37
	F37	F10	F38	F38
share of top 5 techn. fields	51.69%	54.76%	57.39%	62.23%
Herfindahl Index	0.079	0.090	0.090	0.101

Panel C: Jena

Years	1. period 1998-2000	2. period 1999-2001	3. period 2000-2002	4. period 2001-2003
no. of patents	730	814	772	810
no of technological fields	39	38	38	37
ID of top 5 tech. fields	F38	F38	F40	F40
	F40	F40	F13	F38
	F13	F13	F38	F13
	F37	F37	F37	F37
	F10	F10	F10	F10
share of top 5 techn. fields	77.26%	78.37%	77.59%	79.38%
Herfindahl Index	0.087	0.087	0.088	0.093

somehow, the explanatory power of our empirical analysis, thus, we will be careful with the interpretation of our empirical results.

To account for the complementarity of the regional knowledge pools we make use of the IPC, the international patent classification. Each patent shows appropriate IPC numbers which characterize the technological knowhow represented by the patent. The IPC classification allows a detailed view into the technological dimensions of knowledge, as the IPC is much too broad to be used in our analysis, we implement a concordance list developed by Schmoch et al. (2003) in order to reduce the IPC to 43 technological fields that corresponds with NACE industry codes on a 3-digit level.

The registration procedure at the EPO or the DPA allows to list more than one IPC class on a patent. Therefore, it is possible that a patent is classified for more than one of the 43 technological fields. In these cases a patent is assigned to each technological field with the same weight.

To characterize the complementarity of the knowledge base in each region table 7 shows (i) the number of technological fields the actors are engaged in for each period and (ii) the ranking of the 5 most frequented fields (each one identified by a number between F1 and F43) in each region over time.

We first have a look at the range of technology fields covered by each region. Obviously, at any point in time no region is engaged in all of the 43 technological fields. In Northern Hesse the number of active fields is between 36 (3rd and 4th period) and 38 (1st period). Hence, it is a slightly more dispersed than the network in Alpes-Maritime (increase from 32 to 36). The activities in Jena (39 - 37) show a similar spread as those in Northern Hesse.

Looking at the most important technologies addressed in table 7 we list for each region the 5 most frequented fields and find a considerably stability of these structures over time. Looking at the share of patents that have been filed for in the 5 most frequented technological fields for all three regions this is larger than 50%. The highest share if found for Jena, followed by Alpes-Maritime and then Northern Hesse, indicating a higher degree of specialization for Jena compared to the other two regions. The development of this share over time is increasing, rather stronger for Alpes-Maritime and only slightly for the two other regions.

To further illustrate the technological diversity of the three regions and their development, we make use of the the concept of Salter curves developed by Salter (1960). These represent technologies ranked in descendent order by their number of applications. They "allow to judge the extent of mobility within this ranking by comparing the Salter curves pertaining to different periods" (Cantner & Krueger 2004, p.268). Figures 1-3 show a plot for each region. The technologies are descendently ordered according to their frequencies in the first period.

Salter curves of activities in technological fields

Figure 1: Northern Hesse

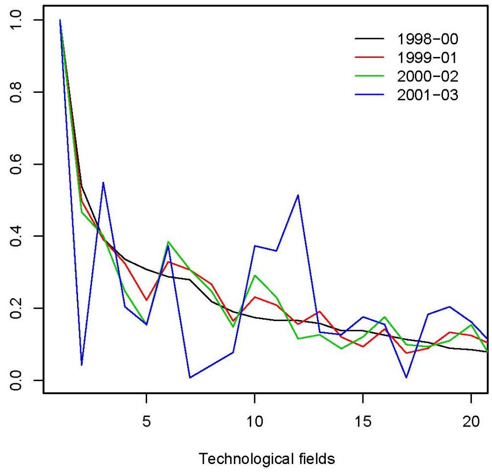


Figure 2: Alpes-Maritime

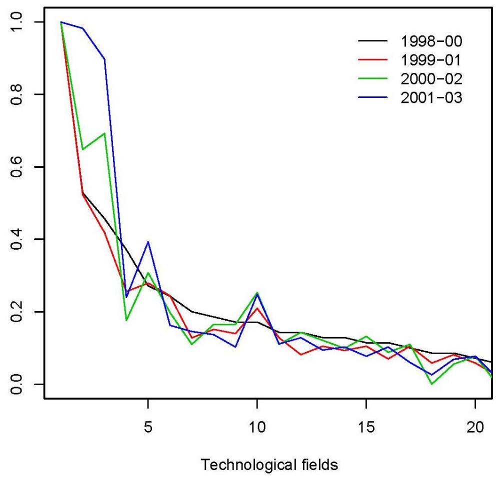
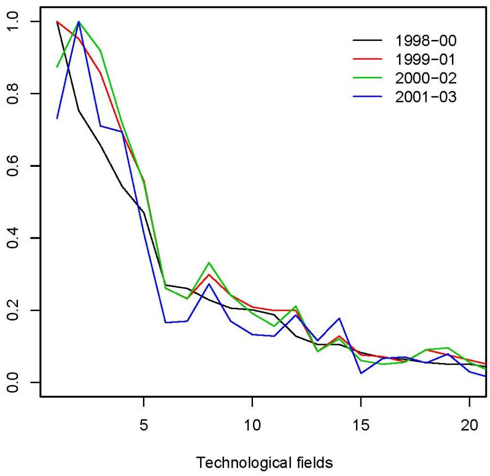


Figure 3: Jena



The figures show that there happens something like a catching up process by the technologies following the leading technology in Jena and Alpes-Maritime while the general ranking of the technologies stays rather constant. In that sense not much of structural change is taking place. In Northern Hesse, however, higher fluctuations are to be observed. This leads to re-ordering of the technologies for that region over time. Consequently, for Northern Hesse the technological composition undergoes a considerable structural change.

The last index indicating the homogeneity of a regional knowledge pool introduced here is the Herfindahl index. By this the issue of specialization is extended to all technologies. Actually this index measures the monopoly power on markets; here it is used to account for the concentration of technologies in a region and thus it measures the homogeneity of the regional knowledge base. The Herfindahl index is here defined as the sum of the squared shares of the patent applications of each technological field in all patent applications. Hence, it can range from 0 to 1 moving from a large amount of small technological fields to a single dominating technology in a region.

Here, Jena and Alpes-Maritime are rather close together (with a tiny lead of Alpes-Maritime) whereas Northern Hesse is much less specialized. The homogeneity of the knowledge pool in Northern Hesse is the lowest within the sample (0.068 in the 1st period) and decreasing over time (to 0.063 in the 4th period). Initially the knowledge base in Jena (0.087) is the most homogenous in our sample; over time it is increasing to 0.093. The knowledge pool in Alpes-Maritime starts at a median level of homogeneity (0.079) and then constantly increases over time (0.101 in the 4th period).

As already mentioned in the theoretical part of this paper, the diversity of the regional knowledge base is used as a proxy for its complementary. This relation is based on the assumption that there are no complementary effect between different technologies, only within them. This issue has to be discussed in further studies, as effects between in addition to effects within technological fields should be taken into account.

5.2 Empirical results

Having characterized the innovation networks in terms of their actors and their components and having described the size and homogeneity of the regional knowledge pools over time, we are interested in the relationships between the degree of interaction on the one hand and the knowledge pool variables on the other. As the number of observation is restricted to three regions and four time periods, we have to neglect regional and time specific effects. As we are interested in the relation between interaction and knowledge pool variables in general, we accept the weaknesses of this procedure at this stage.

Regional interaction is represented by three variables. First, $Ties$ is the number of relationships per actor in the regional knowledge network that comprises labor mobility as well as research cooperation linkages. The more formal research cooperations within a regional innovation system are included in the variable $Coop$ in terms of connections in the co-application network per actor. Finally, we want to use a variable representing, somehow, the connectivity of the whole network. As all three knowledge networks are not fully connected in any time period, the SW variable cannot be used here. So we use the share of non-isolated actors $Noniso$ as an indicator of network connectivity.

The size of regional pool of knowledge spillovers App is represented by the number of patent application within a certain time period. Here, the short time span of our sample prevents us from constructing a regional knowledge stock accumulated over time. The homogeneity of the regional pool is expressed by the Herfindahl index $Herf$.

Table 8: Correlation matrix

	Ties	Coop	Noniso	App	Herf
Ties	1.000				
Coop	0.994**	1.000			
Noniso	-0.745*	-0.698*	1.000		
App	**0.836****	**0.838****	**-0.727****	1.000	
Herf	**0.428**	**0.497***	**0.203**	0.425	1.000

* significant at 5% level; ** significant at 1% level

Table 8 provides the correlation coefficients between the interaction and the knowledge pool variables. Hypothesis 1 suggests the relationship between the amount of regional knowledge and the regional interaction structure. Our results show that the size of the regional knowledge pool *App*is positively correlated to the number of connections in the regional knowledge network $Ties$ (0.836) and to the number of research cooperations *Coop* (0.838), both at the 1% level of significance. More interestingly, *App* is negatively correlated with the share of non-isolated actors $Noniso$ (-0.727). Hence, we conclude that an increasing regional knowledge pool is positively related to an increasing participation in the regional network of those actors who are already connected to other members of the network (either by more formal or more informal oriented interactions). However, it does not enhance the probability of an isolated actor to get connected to the network.

Hypothesis 2 deals with on the importance of the complementarity of the regional knowledge base indicated by the Herfindahl index for the interaction intensity. As it is shown in the last row of table 8, the only significant correlation of the complementarity indicator is found with respect to the more formal oriented interaction variable *Coop*. Thus, we conclude that it is rather the type of interaction labeled cooperation (*Coop*) than the interaction in general (cooperation plus scientist mobility labeled $Ties$) that is related to the complementarity of the knowledge base ($Herf$).

6 Conclusions and future prospects

This paper deals with the concept of the regional innovation system and related concepts explaining individual motives and incentives to engage within a collaborative research project. We apply the methodology of RIS to three regions and we focus on the core of those systems, the networks of innovators. We analyze the development of the respective innovator networks over four overlapping 3-year-periods. The network relationships comprise formal research cooperations as well as informal labor mobility ties. Regional as well as extra-regional actors have been associated to the network.

Although, the observed regions are similar in terms of number of actors and share of internal actors, their networks show a rather different structure and development. The actors of the innovator network in Northern Hesse are rather scarcely connected, most of them are isolated patent applicants. Giuliani (2005) argues that the dispersion and high rate of isolation is up to the cognitive distance between the actors (Giuliani 2005, p.11). Just this constellation can be identified for the region of Northern Hesse, where the dispersion of the regional knowledge base is constantly high over time. In Alpes-Maritime and Jena the share of isolated actors is much smaller. In terms of the overall connectivity we find for Alpes-Maritime an innovator network consisting of numerous components, whereas in Jena most of the actors of the innovator network are connected in one large component. In this sense the regional network in Alpes-Maritime shows a structural similar to the wine cluster of Colline Pisane identified by Giuliani (2005), whereas the regional knowledge network in Jena is similar to the network of Silicon valley analyzed by Sorenson & Fleming (2004). Contrary to this development the homogeneity of the regional pool increases in Jena and Alpes-Maritime.

The final part of the paper has been devoted to the impact of regional pool of knowledge spillovers in terms of size and complementarity on the regional interaction structures measured in terms of number of knowledge network ties, of research cooperations and in terms of the share of non-isolated actors. We find the size of the regional knowledge base to be positively related to the number of ties as well as to the number of more formal oriented cooperation ties. This result contributes to former empirical studies on the regional knowledge base and its impact of interactions such as Fritsch & Franke (2004) or Sharpe & Martinez-Fernandez (2006). This increasing tendency is, however, restricted to those actors which are already engaged in the regional knowledge networks.

Regarding the complementarity of the regional knowledge base under consideration, as indicated by the homogeneity of the regional knowledge base, we find that there are no significant relations between the number of ties and the share of non-isolated actors of the regional knowledge base. Contrariwise, the homogeneity of the regional knowledge base is positively related to the number of cooperations. Thus, we conclude that the technological proximity between member of a regional knowledge network facilitates the more formal oriented interactions, whereas more informal interactions take place. The positive impact of a common technological knowledge base on the cooperation propensity has also been identified on individual (e.g. Mowery et al. 1998, Cantner & Meder 2007) as well as on regional level (Fritsch & Franke 2004, Cantner & Graf 2006).

Due to our restricted sample, we do not want to over-interpret our results. The relations found have to be analyzed on a large sample over a longer time period. Nevertheless our findings imply that regional actors need to have a common technological knowledge base to interact in more formal oriented ways.

Our comparative case study provides first insights into the development of regional innovation systems and possible driving forces. Based on our findings, we will concentrate on more formal oriented interactions when analyzing the relationship between regional interaction structure and regional knowledge base more deeply. Furthermore, the role of regional proximity in contrast to technological proximity has to be discussed in further studies on firm as well as on regional levels.

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