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Martina Kauffeld-Monz
Michael Fritsch

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Impressum:

Friedrich Schiller University Jena
Carl-Zeiss-Str. 3
D-07743 Jena
www.uni-jena.de

Max Planck Institute of Economics
Kahlaische Str. 10
D-07745 Jena
www.econ.mpg.de

Who are the brokers of knowledge in regional systems of innovation? A multi-actor network analysis

Martina Kauffeld-Monz*

Michael Fritsch**

Abstract

The discussion on regional innovation systems emphasizes the duality of local and global links. While the former enable effective knowledge exchange between regional actors, the latter are considered to provide regional systems with knowledge diverse to their knowledge base. Our empirical analysis of 18 German regional innovation networks highlights the importance of public research organizations for inter-regional knowledge exchange. The broker and gatekeeper function of public research organizations may be particularly important in lagging regions that typically suffer from a lack of large firms who often assume the role of "gatekeepers of knowledge".

Keywords: Regional systems of innovation, innovation networks, knowledge broker, gatekeeper

JEL classification: D83, D85, L14, 018

* Institute for Urban Science and Structural Policy (IfS Berlin), Germany. kauffeld-monz@ifsberlin.de

** Friedrich Schiller University Jena, German Institute for Economic Research (DIW-Berlin), and Max Planck Institute of Economics, Jena, Germany. m.fritsch@uni-jena.de

1 Introduction

The concept of regional innovation systems emphasizes that innovations result from effective linkages between the knowledge generating, the knowledge transferring, and the knowledge exploiting components of these systems (Braczyk, Cooke et al. 1998; Cooke 2002; Etzkowitz and Klofsten 2005). Regional networks of innovation are considered as an adequate instrument to strengthen regional innovation systems because they may foster personal fact-to-face contacts that facilitate the exchange of uncodified knowledge (Longhi 1999; Dahl and Pedersen 2004). Moreover, regional network structures can accelerate trust building within R&D collaborations that typically require the mutual disclosure of competition relevant knowledge (Das and Teng 2001; Nooteboom 2003). These advantages of regional networks are regarded as one of the main causes of localized knowledge spillovers (Audretsch and Feldman 1996; Breschi and Lissoni 2001). Regional networks and localized knowledge spillovers may explain why knowledge diffusion is concentrated close to the locus of knowledge generation but also why innovation activity is found to be clustering in space (Feldman 1994; Audretsch and Feldman 1996; Oerlemans, Meeus et al. 2001; Malmberg and Maskell 2002).

Regional innovation networks may not only promote knowledge flows that are based on direct relations, but they can also contribute to knowledge diffusion by indirect links resulting from brokerage. Brokers are actors in the network that transfer knowledge between organizations that are not linked directly (Nooteboom 2003). Such an indirect transfer may also involve a transformation of the respective knowledge. Moreover, brokers have the opportunity to derive their own benefits from their intermediary position by re-combining and exploiting knowledge that they draw from various contexts (Hargadon and Sutton 1997).

Whereas trust based local network relations most notably are conducive to the effectiveness of knowledge exchanges, global links may provide the regional innovation system with knowledge that differs from its knowledge base. Thus, global links are seen to be very important with regard to the acquisition of innovation related knowledge (Camagni 1991). But many of the small firms lack access to global knowledge sources due to their limited resources. It is often argued that large firms can act as “knowledge brokers” and “gatekeepers of knowledge“ by supplying the network organizations with knowledge they have attained over the course of their global exchange processes (Lazerson and Lorenzoni 1999; Biggiero 2002; Agrawal and Cockburn 2003; Munari, Malipiero et al. 2005; Morrison 2008). However, in lagging regions such large and globally linked firms are often under-represented or missing entirely. Therefore, the question about what the possibilities are to compensate for this deficit arises. One may ask to what extent public research organizations may fill this gap, i.e. provide access to global knowledge sources and act as knowledge gatekeepers (Fritsch and Schwirten 1999; Varga 2000)?

Our study focuses on knowledge exchange processes that took place between 338 organizations that were involved in 18 regional networks of innovation. The organizations collaborated in R&D over a period of at least five years. All regions in our study can be characterized as lagging according to the criteria applied by the European Cohesion Policy. These regions especially lack intensively innovating large firms. We try to identify central groups of organizations with regard to knowledge exchanges within the networks. The investigation involves direct relations as well as indirect links that result from broker positions. We pay special attention to public research organizations as a knowledge source and as “gatekeepers of knowledge”. In the following section, we discuss the relations between local and global knowledge sourcing in more detail. The research design and the respective data sources are explicated in section 3. The results are presented and discussed in section 4. Finally, we summarize our results and draw conclusions (section 5).

2 The relation between local and global knowledge sourcing

2.1 The importance of local links and embeddedness for innovation

In knowledge intensive economies, innovation is considered as a key driver for economic development. Several studies on localized spillovers highlight the pronounced regional dimension of innovation processes (Jaffe, Trajtenberg et al. 1993; Feldman 1994). The main reason for this localization of innovation processes is the benefit of spatial proximity that involves the possibility of frequent face-to-face contacts. This type of contact fosters multi-dimensional communication (verbal, physical, context specific, non-intentional) that is essential for trust building and for the transfer of complex and uncodified knowledge (Storper and Venables 2004). Generally, processes such as the development of new partnerships, periodically arising coordination requirements, the discussion of ill-defined problems, re-evaluation of projects as well as strengthening of social relationships may be more effective if they are based on direct personal contacts (Fontes 2005). Spatial proximity is not only conducive to dyadic exchange relations, but it may also foster collective learning processes (Boschma and Lambooy 1999; Capello 1999; Lawson and Lorenz 1999) and may permit higher flexibility concerning the pooling and bundling of resources (Sabel 1989). In this respect, relations that are embedded in institutional arrangements such as regional innovation networks can be considered as a precondition of effective successful regional systems of innovation (Cooke, Heidenreich et al. 2004).

The scope and intensity of personal relations within a dynamic regional innovation system is the basis for the emergence of “local buzz” (Bathelt, Malmberg et al. 2004; Storper and Venables 2004). This term refers to the idea that in a specific dynamic milieu, many processes that entail rich information and inspiration do emerge simultaneously (Bathelt, Malmberg et al. 2004). Local buzz refers to the co-localization of individuals and firms within the same industry and corresponds to Marshall’s “industrial atmosphere” (Marshall 1927). Local buzz is generated by specific information and their continuous update, by intended as well as unintended learning processes as the result of purposeful and casual meetings, by similar patterns of interpretation as well as by shared cultural traditions and industry specific practices (Bathelt, Malmberg et al. 2004).

The organizations involved in a regional network do not only benefit from local buzz, but they also contribute to its emergence. Local buzz, however, does not come about without specific investments. The development of robust inter-organizational relations for innovation, the establishment and maintenance of customer-supplier relations, the participation in networks and numerous discussions require time and resources. Thus, the existence of local buzz, although spontaneous and fluent by nature (Bathelt, Malmberg et al. 2004), does not only result from the mere co-location of individuals and organizations, but it is based on their active participation in networking (Crowley 2007). This may explain why knowledge does not diffuse evenly within a region but rather diffuses within a core group of actors that are characterized by high absorptive capacities (Giuliani and Bell 2005). Several studies that apply different methodical approaches confirm this finding by identifying co-operations between public research institutions and private firms as a crucial factor in the operation of regional innovation systems (Breschi and Lissoni 2001; Waters and Lawton-Smith 2002; Agrawal and Cockburn 2003; van Looy, Debackere et al. 2003; Fritsch 2004; Fritsch and Slavtchev 2007).

2.2 The problem of lock-in

Besides the advantages of socially embedded relations such as regional innovation networks, embeddedness may also lead to severe problems (Merton 1936; Lazerson and Lorenzoni 1999). One particular problem is the danger of a regional lock-in situation that may result in technologically inferior solutions (Grabher 1993; Glasmeier 1994; Boschma 2005). When everyone in a network is applying the same routines and is exposed to the same ideas, the opportunity to learn from each other is rather limited (Nelson and Winter 1982). Furthermore, intensive regional network relations involve the danger of producing “blind spots“ in terms of insufficient attention being paid to the strategies and competences of competitors external to the region (Pouder and St. John 1996). Thus, local networking and knowledge accumulation can lock the local actors in obsolete, non-competitive technological trajectories (Dosi 1982; Camagni 1995; Capello 1999). Especially highly specialized regions (Graf 2007) and technologies with a pronounced international orientation such as biotechnology (Gertler and Levitte 2005) are faced with this risk and require intensive transfers of knowledge and information across regional borders. Therefore, it is argued that successful innovation is based on the appropriation of specialized regional know-how, on the one hand, and globally dispersed knowledge, on the other hand (Bathelt, Malmberg et al. 2004). A global orientation typically is found with innovation intensive firms in advanced stages of development (Geenhuizen 2007). These findings correspond to the industry-life-cycle and the cluster-life-cycle-hypothesis, suggesting that economic activity is more geographically dispersed as the industries mature (Swann 1998; Tichy 2001).

All these arguments and observations suggest that inter-regional flows of information and knowledge are important for regional innovation processes (Camagni 1991). Especially they are advantageous if they are appropriately linked to local buzz (Scott 1996; Asheim and Isaken 2002; Bathelt, Malmberg et al. 2004). The simultaneous exploitation of local and global knowledge sources requires adequate interfaces between the local and the global sphere (Kim and Tunzelmann 1998; Graf 2007). However, the identification of global knowledge sources as well as development and maintenance of global contacts involve considerable financial and personal capacities, which often are not available in small- and medium-sized firms (SMEs) (Lindholm-Dahlstrand 1999; Grabher 2002; Fontes 2005). This leads to the question how such firms can attain essential knowledge that is not available within their region?

We suppose that many SMEs obtain access to external knowledge by connecting to regional innovation networks that include actors that are well linked to global knowledge sources. Such “gatekeepers” (Allen 1977) or “boundary spanners” (Sapsed, Grantham et al. 2007) play an important role in regional systems of innovation as they absorb globally dispersed knowledge and introduce it to regional innovation processes (Bathelt, Malmberg et al. 2004). The functions of the gatekeepers are to monitor the external environment and translate the technical information into a form that is understandable to the local organizations (Cohen and Levinthal 1990). Thus, gatekeepers help to extend the regional scope of new ideas (Wink 2008). As a result, the gatekeepers can make a considerable contribution to the acquisition, generation, and diffusion of knowledge (Giuliani and Bell 2005). They may also compensate for structural deficits of new industries, which in their early stages of development are faced with institutional weaknesses (Carlsson 1994;

Howells 2006). Hence, gatekeepers can be regarded as a precondition for an appropriate performance of organizations (Cross, Borgatti et al. 2002).[1]

Large firms are often found to fulfill the role of a gatekeeper because of their interregional orientation, which includes international contacts and rich expertise (Albino, Garavelli et al. 1999; Boari and Lipparini 1999; Lazerson and Lorenzoni 1999; Biggiero 2002; Munari, Malipiero et al. 2005). Their knowledge may be transferred to local SMEs by involving them in R&D projects. Through co-operation with large firms, SMEs can be connected to basic research and may gain access to large firms' distribution channels (Knorringa 1996). A number of studies conclude that in particular multinational enterprises' access to international markets of technology is of crucial importance for a local economy (Veugelers and Cassiman 1999; Biggiero 2002). Thus, large firms are important elements within regional innovation networks because they convey globally dispersed knowledge into their regional network of customers and suppliers (Morrison 2008).

3 Research design

3.1 General approach

Lagging regions tend to be characterized by a relatively high share of SMEs; thus, larger firms that could act as gatekeepers of knowledge are rare or completely missing (Fontes 2005). This study investigates if public research organizations can compensate for this deficit. From patent data analyses, we know that there are often many links between public research organizations and firms that possibly involve knowledge flows (Cantner and Graf 2006; Graf and Henning 2008). The effectiveness of a gatekeeper function within regional innovation networks is based on the following preconditions:

- The gatekeeper organization is well linked to global knowledge sources as well as to local organizations (Giuliani 2005; Munari, Malipiero et al. 2005).

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[1] At the firm level, Tushman and Katz (1980) found that gatekeepers positively affect the performance of R&D projects within R&D units.

- The gatekeeper organization holds high absorptive capacities in the relevant knowledge domains and has adequate capacities to accumulate and store this knowledge (Lazerson and Lorenzoni 1999; Munari, Malipiero et al. 2005; Graf 2007).

- The gatekeeper possesses the capacity, the ability, and is willing (incentive structure) to transfer his knowledge into the region and to share it with local partners (Harada 2003; Cranefield and Yoong 2007).

We suppose that public research organizations cope with these requirements in many respects. Public research organizations possess a large stock of R&D personnel and have access to globally dispersed knowledge as the scientific community tends to be well connected internationally. Moreover, most if not all public research organizations have a knowledge transfer mission and are characterized by an “open science mentality“ and many of them are also familiar with knowledge transfer due to their teaching activity. Hence, public research organizations are principally qualified to fulfill a gatekeeper function (Owen-Smith and Powell 2004; Graf 2007). In contrast to the public research organizations’ open science mentality, private firms often share their knowledge only with a strictly selected group of closely connected partners (Morrison 2008). As a result, the diffusion of their knowledge tends to be rather restricted. The differences between public research organizations and for-profit organizations mainly stem from a sharply divergent selection environment (Owen-Smith and Powell 2004) and their disparate approaches to the dissemination and use of scientific findings (Dasgupta and David 1987; Dasgupta and David 1994) that makes new knowledge flowing out of universities more readily available than the knowledge from commercial organizations is (Jaffe, Trajtenberg et al. 1993; Owen-Smith and Powell 2004).

There may be a number of impediments for the transfer of knowledge and technology from public research to private businesses such as information deficits and problems of access, technological mismatches, restricted absorptive capacities of the firms as well as considerable requirements of further investments due to the proof-of-concept stage of academic inventions (Schmoch 1999; Harper and Rainer 2000; Schmoch, Licht et al. 2000; Hall, Link et al. 2001; Franzoni and Lissoni 2008). Such problems can, however, be considerably reduced if public research organizations and private firms are connected within a regional innovation network.

Since the gatekeeper function includes the more general characteristics of acting as a knowledge broker (with the exception of the linkages to global knowledge sources), our empirical analysis will first focus on brokerages before investigating who the gatekeepers are and how they fulfill their function in the innovation networks under study.

3.2 Hypotheses

We suppose that public research organizations transfer a considerable amount of information and knowledge to their network partners (hypothesis 1). For this reason, they can be regarded as a central group of actors in an innovation network (hypothesis 2). This prominent position with regard to knowledge transfer is closely related to the network centrality of public research organizations, which results in the exertion of broker positions. A broker position emerges if one organization links to other organizations that are not directly connected. The benefits resulting from brokerage may be diverse. Among these benefits are the bridging or mediating agents that may result in a reduction of problems caused by information asymmetry (Nooteboom 2003).

Brokers may act as arbitrators of contracts and can help to prevent misunderstandings (Burt 2005). A broker with a good reputation within the network may help to control the risk of involuntary spillovers and mediate the building and maintenance of trust (Zucker 1986; Shapiro 1987; Nooteboom 2003). Clearly, broker positions may entail benefits for the brokering organization as well as for the organizations that are linked to the broker. Thus, we expect social returns (brokers generate additional knowledge transfer to their network partners) as well as private benefits (brokers acquire additional knowledge) resulting from brokerage (hypothesis 3). To a certain degree, the private and the social benefits may occur independently: The private benefits result from the application of knowledge absorbed from different networks partners and contexts in the broker organization (Hargadon and Sutton 1997).

The social benefits arise from the knowledge that the broker is passing through from one organization to another. Public research organizations are not only regarded as important interfaces in respect to the knowledge exchange within a network, but, compared to small firms, public research organizations possess good access to global knowledge sources (hypothesis 4). This may result in additional transfer of such knowledge to network partners, i.e. the fulfillment of a gatekeeper function (hypothesis 5).

3.2.1 Data and Measurement

3.2.2 Data

Our analysis is based on detailed information about 18 East German regional innovation networks that were initiated in 1999. The networks have been selected in the promotion policy program “InnoRegio”, which aimed to improve regional innovation systems in lagging regions (see Eickelpasch and Fritsch 2005 for details about this program). The InnoRegio program tried to stimulate the formation of innovative networks that involved private firms as well as public research organizations (Eickelpasch, Kauffeld et al. 2002a; Eickelpasch, Kauffeld et al. 2002b; BMBF 2005; Eickelpasch and Fritsch 2005). The networks under study have a number of common features that result from the guidelines and conditions of the policy program. Since one of these conditions was that most of the organizations belonging to the network had to be located in spatial proximity, the distances between partners tend to be rather small with a maximum of about 50 kilometers.[2] The regions involved suffer from similar disadvantages such as low income and productivity, lack of larger firms, etc. that are largely a result of the transformation process in East Germany, the former German Democratic Republic (GDR) (Kronthaler 2005). For these reasons, the networks should be highly comparable. Differences between the networks particularly concern the industries and technologies[3] involved as well as the number and the character of organizations. About 60% of the organizations were private firms. Universities consist of 10% of the total, and

[2] All of these regions are of about the same geographical size.

[3] e.g., bio-technology, medical technology, automotive, innovative textiles, phytopharma, health industry, musical instruments

about 16% of the actors were public or private non-university research institutes.

About 20% of the organizations involved were vertically linked by buyer-supplier relations. Most of the firms involved in the networks are small or medium-sized: 50% have less than 20 employees and only 10% have more than 100 employees. The service sector firms, which contribute to about 40% of the private firms in the networks, are mainly engaged in engineering services and in R&D. The manufacturing firms include a high proportion of mechanical engineering, medical engineering, measurement engineering, and control technology as well as textiles (Eickelpasch et al. 2002b). The firms in the selected networks exhibit an above average performance with regard to R&D, the introduction of new products on the market, and they consider themselves to be more competitive than most of the other suppliers in the respective market (Eickelpasch et al. 2002b). For this reason, there is a certain sample selection bias with regard to innovation attitudes, innovative capabilities as well as expectations about future growth.

3.2.3 Network construction and network measures

The data were gathered by postal questionnaires in the year 2004 that resulted in a rather high response rate of about 80%. For network construction, each actor of a network was asked to name his most important partner(s) within the network. On average, actors named three network members, in most cases partners of their actual R&D projects.[4] Organizations that participated in a network but did not respond the questionnaire have been included in the analysis if at least two of the responding actors named the non-responding organization as one of their "most important partners". In this manner, we tried to capture the complete network. On the basis of these links, we generated a network matrix for each network. We assume that knowledge and information is exchanged along these links.[5] Altogether, we have 338 organizations that have

[4] More than 500 R&D-projects were conducted and granted in the program. They differ considerably in regard to their research topics, duration, financial volume, and partners involved. However, the subsidies were basically restricted to the early stage of innovation.

[5] We assume that an organization has transferred information and knowledge to a certain network member if it was named by this network member as an important partner. Absorption

been attributed to 18 different regional networks of innovation.[6] As an example, figure 1 shows a network graph for one of the innovation networks in our sample. This network consists of 54 actors, and they have been attributed to 32 different organizations. Three of the actors named neither partners, nor were they named by other actors as most important partner (isolates). Thus, we had to exclude them from the network analysis that was finally conducted on the basis of 29 organizations (nodes).

For each of the 18 networks, we calculated several measures that indicate centrality of an organization and are supposed to be positively correlated with information and knowledge exchange. These measures are:

- *Degree*: The number of an organizations' direct links of knowledge transfer to other organizations in its network. Often the number of degrees is considered to be an indicator of prestige (Jansen 1999). An organizations' direct links as a whole are called "ego network";

- *Betweenness* is a distance-based measure. It describes an essential feature of innovation networks. Unlike degree-based measures, distance-based measures include indirect links within the network. Betweenness reports the frequency an organization (i) is located on the „shortest path"(geodesic distance) of two other organizations (jk) that are not linked directly. Betweenness may indicate an organizations' ability to absorb information (Owen-Smith and Powell 2004) that can be transferred to network partners.

- *Broker*: In contrast to betweenness, only the direct links of an organization (its ego network) are included for calculating the broker measure. A broker position arises if an organization links two organizations of its ego network that are not linked directly. In such a case, the brokering organization may act as a connector of different contexts. This measure is the number of organizations in the ego network of an actor that are indirectly linked by this

takes place if an organization named a certain network member as an important partner. Thus, mutual information and knowledge exchange only occurs if two organizations name each other as important partners.

[6] Among these are 142 manufacturing firms (42%), 80 service firms (24%), 35 universities (10%), 27 non-university public research organizations (8%), 28 private research organizations (8%), and 20 other.

actor.[7] While betweenness may indicate an organizations' ability to absorb and transfer *information,* the broker measure may be more suitable for indicating *knowledge* flows. Unlike information, knowledge hardly passes a great number of nodes (organizations) that are not linked directly because knowledge is more complex than information and often involves tacit components.[8] By applying the broker measure, we suppose that knowledge can be passed via at least one interface (the broker).

The data include indicators for the transfer and for the absorption of both information and knowledge. The extent of transfer as well as absorption has been measured on a 5-point Likert scale ranging from "very few" to "very much" (table 1 in Appendix). With regard to the different types and dimensions of knowledge (Nonaka 1991; Cowan, David et al. 2000), our analysis focuses mainly on technological know-how exchanged between the organizations, measured by "the extent of technological support" provided to or received from network partners (table 1 in Appendix). However, there may also be some degree of "know-what" (declaratory/factual knowledge) as well as "know-why" (scientific knowledge) included in the exchanges. We have strong indication from in-depth interviews with selected network members that a considerable part of the knowledge exchanged is of a tacit nature.

Our analysis of gatekeeper effects is based on information about the existence and the frequency of inter-regional R&D cooperation in basic research, product innovation, and process innovation measured on a 5-point Likert scale ranging from "not at all" to "very often" (table 1 in Appendix). Moreover, the data allow for running the analyses separately for different types of actors that represent fundamental elements in the regional innovation system approach: Universities, public non-university research organizations, private research organizations, manufacturing firms, and service firms.

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[7] See section 4.2.2 for measurement details.

[8] Probably for this reason, Ahuja (2000) found that indirect connections among firms positively affect innovation, although the effect is moderated by direct ties.

4 Results

4.1 Knowledge transfer of public research

Our results point to a prominent role of public research (universities and non-university public research organizations) with respect to the exchange of knowledge within the networks under study. This can be illustrated by a network graph for one of the networks under study (figure 1). Based on a 5-point Likert scale (table 1 in Appendix), we found that the knowledge transfer of public research organizations amounts to 4.1. Private firms show a significantly lower value of 3.2 (statistically significant at the 5-percent level; Mann-Whitney-Test).[9]

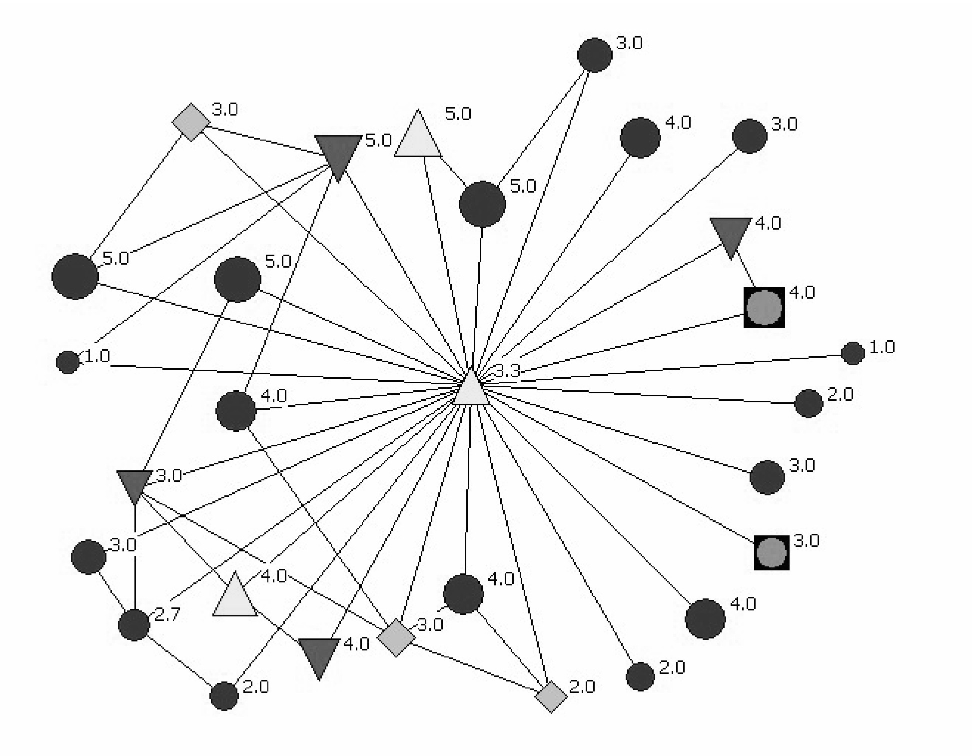
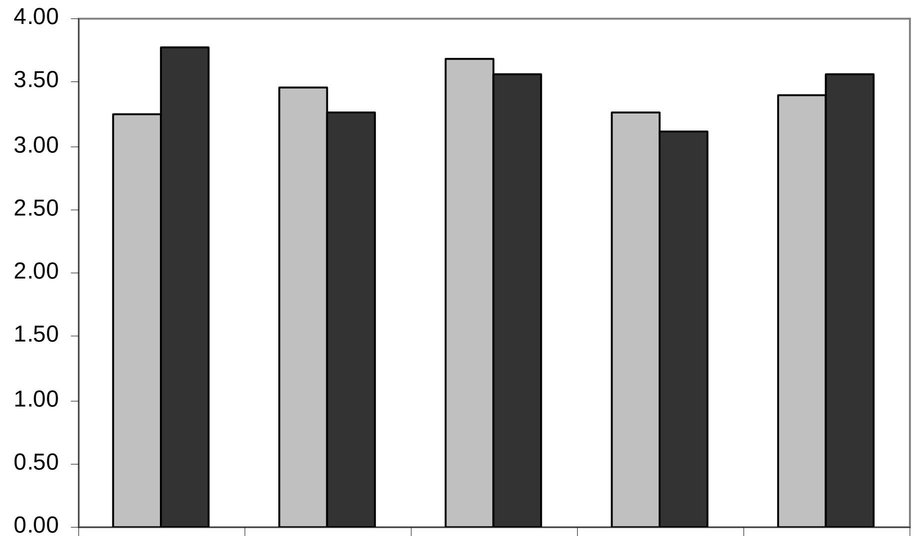


Figure1: Knowledge transfer within one of the networks studied

Nodes = organizations; lines = exchange relations; size of symbols = extent of knowledge transfer to network partners (means per organization; measured at a scale from 1 to 5). Circle/circle in box = manufacturing firms/service firms; up triangle = universities; down triangle = public non-university research organization; diamonds = institutions of basic and advanced training and other.

[9] The private firms' share of the absolute volume that has been transferred (in total 176) amounts to 48% (public research organizations = 43%). Thus, the numerical dominance of private firms does not crowd out the public research organizations' meaningful transfer value.

The network we pictured in figure 1 is more a typical than a special case, which is shown by the results for the whole sample (figure 2). However, we have convincing evidence that public research organizations by no means can be considered as a homogeneous group in regard to knowledge exchange: The universities are the group of actors that on average transfer the highest amounts of knowledge to their network partners, closely followed by the service firms. Similarly, they gain considerable benefits in terms of knowledge absorption from network partners. However, non-university public research organizations cannot be regarded as a central source of knowledge. In general, we found the non-university public research organizations to be poorly involved into exchange processes of their regional networks.[10] The relatively intense participation of the universities in the transmission as well as in the absorption of knowledge strongly indicates that the respective innovation processes were not linear in character but were characterized by pronounced feedback-loops.



	Manufacturing firms	Service firms	Universities	Non-university research organizations	Private research organizations
Knowledge transfer	3.25	3.46	3.68	3.27	3.40
Knowledge absorption	3.78	3.27	3.56	3.12	3.56

Figure 2: Transfer and absorption of knowledge by different groups of actors

[10] The knowledge transfer as well as the knowledge absorption of non-university public research organization turns out to be significantly lower than that of the universities (at the 5-percent level; Mann-Whitney-Test).

4.2 Centrality of public research organizations

4.2.1 Degree and betweenness

As outlined above (section 3.3.2), an organizations' centrality within a network can be measured by several indicators. We found strong evidence that public research organizations hold a more central position in the networks than the private sector firms. While public research organizations maintain about 4.5 direct partnerships (so-called degree) within their regional innovation network, the private sector firms reported to maintain on average 2.9 such relationships (significant at the 1-percent level; Mann-Whitney-Test). Certainly, this indicates resource restrictions of SME. The "normalized degree centrality"[11] shows that private firms on average are linked with 14% of the network organizations, whereas public research organizations are linked with 25% of those.

Due to resource restrictions, only a limited number of direct ties (partnerships) are possible at a certain point of time. One of the fundamental advantages of networks is considered in the potential of additional indirect links whose connection by intermediaries allows the transmission of information and knowledge. Distance-based network measures like "betweenness" account for such indirect links. The betweenness measure indicates how often an organization (i) is located at the „shortest path" (so-called geodesic distance) of two other organizations (jk) that are not linked directly. It is evident that public research organizations show a significantly higher normalized betweenness (11.1) than the firms (2.9).[12] In other words: While the private firms are located on nearly 3% of all "shortest paths" in their network, the public research organizations are on about 11% of them. Such positions are seen as a specific feature of innovation networks. Betweenness is supposed to indicate an organizations' possibility to absorb information from network partners and to transfer it to others. Indeed, we found betweenness positively related to the

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[11] The standardized measure corresponds to the degree of an organization divided by the maximal possible degree that is calculated on the basis of the total number of organizations, multiplied by 100. Thus, the standardized measure takes the network size effects into consideration.

[12] Statistically significant at the 1-percent level (Mann Whitney-Test).

transfer of information to network partners. However, this relationship is statistically significant only with respect to the private firms, not for the public research organizations.[13] Since there is strong evidence that the universities are highly involved in the information transfer as well (Fritsch and Kauffeld-Monz 2008), we suspect that the statistical insignificance of the relationship between universities' betweenness and the transfer of information to their network partners may be due to the relatively small number of entities in our analysis (35 universities). Remarkably, we find no indication in our data for a relationship of the betweenness and the *absorption* of information. Obviously, the information that has been transferred was passed through to network partners rather than being applied within their own organizations.

4.2.2 Broker positions

The broker measure is limited to the direct links of an organization, the ego network. A broker position emerges if an organization (i) links itself to other organizations (jk) of its ego network that are not connected directly. The broker organization, therefore, is an immediate neighbor in the network. This permits the transmission of complex and personal knowledge that is usually restricted to direct exchanges between the organizations (jk). However, a broker organization may also re-combine the knowledge it acquires from different network partners and may, in this way, generate new knowledge.

First, we calculated the number of broker positions for each organization.[14] In the network that is shown in figure 3, a university holds an outstanding central position (upwards-facing triangle in the middle of the graph). Because

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[13] The correlation coefficient is 0.125 (statistically significant at the 5-percent level). With respect to the universities, we found a positive, but insignificant, correlation coefficient of 0.144. The correlation coefficient for the non-university public research organizations had a non-significant negative value.

[14] The public research organization that is located at the middle of the top in figure 3 may serve as an example. For calculating the broker measure, the organizations' direct relations (ego network) are taken into account which amount to 5. Thus, for this actor a maximum of 20 broker positions (n * (n-1)) is attainable. According to figure 3, this public research organization is linked to 5 pairs of organizations that are not connected directly. Additionally, the organization connects 4 other pairs of organizations that are not linked reciprocally but only in one direction. Such links in which knowledge is only transferred in one direction are only counted as 0.5. As a result, the calculation of the number of broker positions accounts for the exchange directions. Altogether, the examined public research organization attains 7 broker positions (5 + (4*(0,5)).

the partner-organizations of the universities' ego network are not well connected with each other, the university has a huge number of broker positions (367). Furthermore, two non-university public research organizations (downwards-facing triangles) hold central positions and show a considerable number (7 each) of broker positions. A large number of the firms (circles) are without any broker position. The largest number of broker positions that a firm holds in this network is 3. According to our data, a typical broker firm is characterized by a relatively large firm size and high R&D capacities. Additionally, it has maintained co-operative relationships with several of the network partners before the InnoRegio program was established. Unlike firms that do not assume a broker position in their network, the typical broker firm has relatively little concerns with regard to unintended knowledge spillovers: While 12% of the manufacturing firms without broker positions do not patent because they fear that this could jeopardize their knowledge advantage, only 6% of the manufacturing firms with broker positions state that this prevents them from patenting.[15]

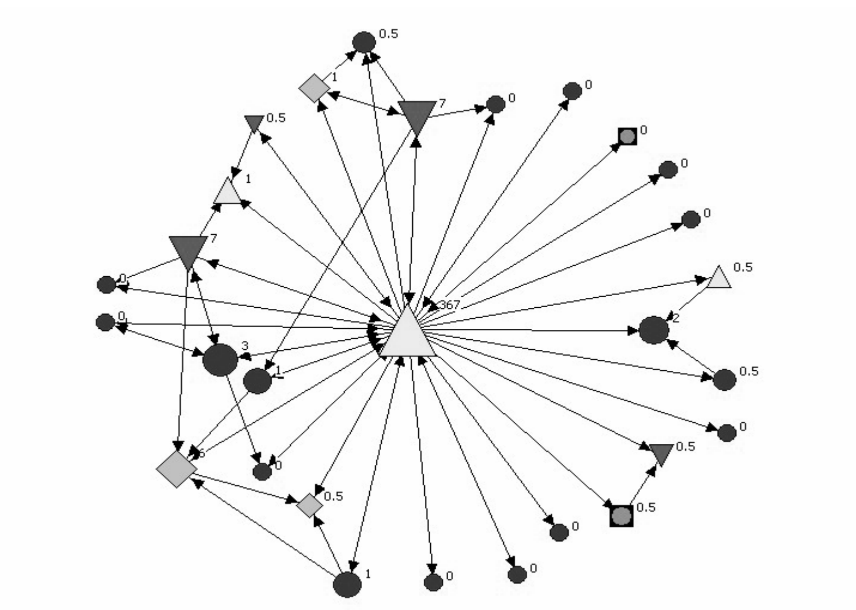

Figure 3: Number of broker positions

Nodes = organizations; lines = exchange relations; arrowheads = exchange direction(s); size of symbols = number of broker positions. Circle/circle in box = manufacturing firms/service firms;

[15] All mentioned differences between brokers and non-brokers are statistically significant at the five-percent level of significance.

up triangle = universities; down triangle = public non-university research organization; other boxes = institutions of basic and advanced training and other.

The results for the whole sample (18 networks) indicate that 80 percent of the universities, 67 percent of non-university public research organizations, and 75 percent of the private research organizations have at least one broker position. For the manufacturing firms, this share is 56 percent and for the service firms it is 81 percent. Moreover, we found differences between these different groups of actors concerning the number of broker positions per organization: Universities hold on average 22.15 broker positions, non-university public research organizations hold 5.65, private research institutes hold 18.9, manufacturing firms hold 2.6, and service firms have 4.0 broker positions. From these findings, one can argue that public research organizations are central nodes in regional networks of innovation.[16] This means that especially the ego networks of the universities are rife with organizations that are not (well) linked with each other. Altogether, these findings confirm the central position of public research organizations, especially of the universities, in the innovation networks under investigation.

4.3 Relations between the broker position and knowledge exchange

The network approach implies that information and knowledge flow not only results from direct ties, but also from indirect links that are generated by brokers. As outlined in sections 3.2 and 3.3.2, we suppose broker positions to be positively related to knowledge exchange because they indirectly expand the access to knowledge sources, but broker positions only result in broker functions if the broker finally conveys knowledge from one organization/context to another (Sapsed, Grantham et al. 2007).

With respect to universities and manufacturing firms, the mean values as well as the results of non-parametric tests show (at the 5-percent level; Mann-Whitney-Test) that the existence of at least one broker position has a positive effect on the extent of knowledge absorbed and on the extent of knowledge that

[16] In three out of the 18 networks, one university has an enormous number of broker positions (367, 94, and 92.5 broker positions, respectively).

is transferred to network partners (figure 4). Apparently, universities' and manufacturing firms' broker positions result in a broker function. Thus, universities as well as manufacturing firms are able to draw private benefits (higher level of knowledge absorption) from a broker position, and they also generate social benefits in terms of a higher level of knowledge transferred to other members of the network.[17] With respect to the non-university research organizations, we found no relationship between their amount of knowledge transfer to network partners and the existence of a broker position, whereas their amount of knowledge *absorption* increases, even though not significantly (figure 4).

[17] Those seven universities that do not assume a broker position in the networks under study also show an extremely low level of knowledge exchange with network partners. In cases where a university does not have at least one broker position in a network, the innovation activity of the network does not predominantly rely on academic knowledge. We know from our inquiry that these universities do also exchange knowledge with other actors, but these actors do not participate in the respective network.

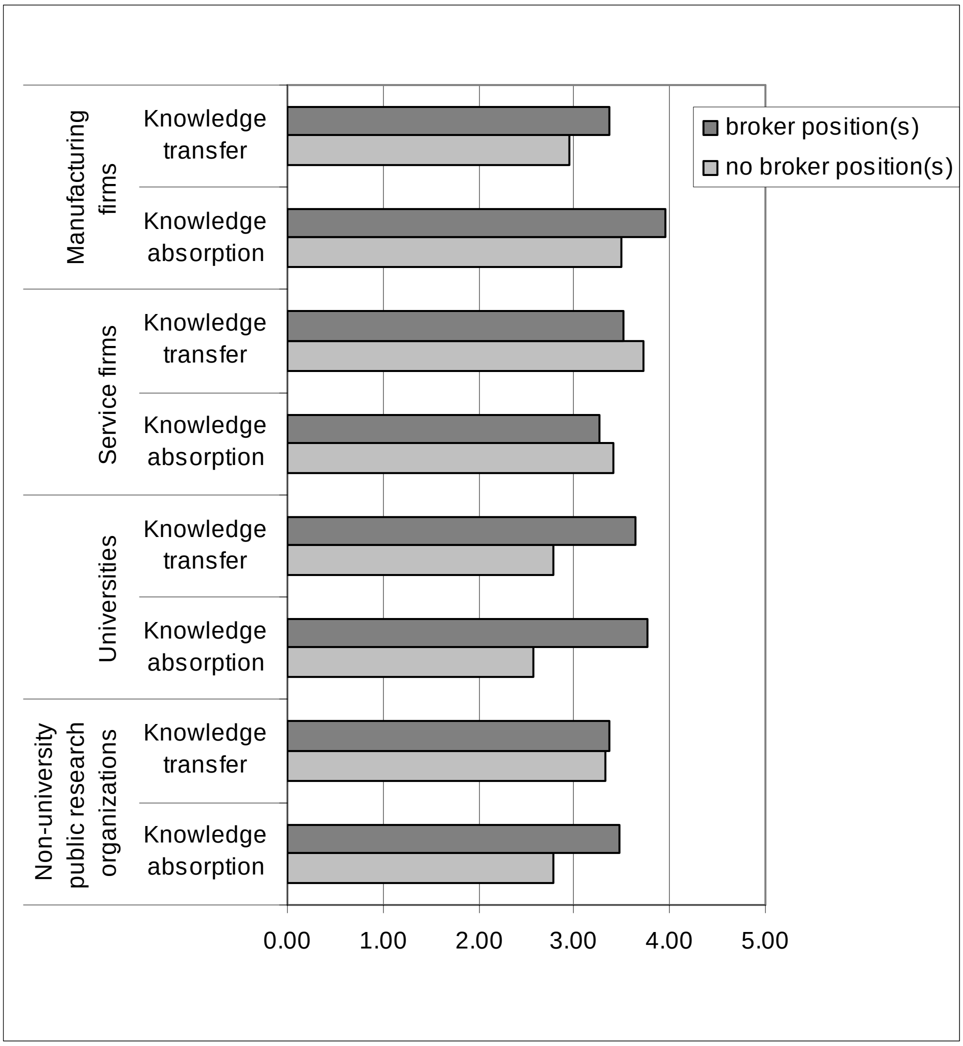

Figure 4: Extent of knowledge exchange by actors in a broker position and without a broker position

In a further step of analysis, we also examined the relation between the number of broker positions that an organization assumes in its network and its extent of knowledge exchange with network partners. The respective correlation coefficients (table 1, column 3) indicate that universities transfer a higher amount of knowledge to their partners as their number of broker positions increases. The same is true for the manufacturing firms in our sample. Unlike the mere existence of a broker position (figure 4), the increasing number of broker positions does not seem to be positively related with knowledge absorption for these two types of actors (table 1, columns 1 and 3). The correlations suggest that an increasing number of broker positions does not result in private benefits in terms of more knowledge absorbed but in social benefits that emerge through additional knowledge transfer to network partners. For the service firms as well as for the non-university public research organizations, the number of broker positions appears to be unimportant for their extent of knowledge exchange (table 1).

Table 1: Correlation between the number of broker positions and knowledge exchange (kendall-Tau-b coefficients)[1]

	Manufacturing firms (N = 137)	Service firms (N = 77)	Universities (N = 35)	Non-university public research organizations (N = 27)
Knowledge transfer	.145**	- .124	.295**	-.143
Knowledge absorption	.110	- .058	.174	.026

[1] The number of broker functions is normalized by the size of an organizations' ego network

* = significant at 10% level; ** = significant at 5% level; *** = significant at 1% level

4.4 The gatekeeper function

As outlined above (section 3.1), a gatekeeper function requires regional embeddedness as well as access to inter-regional knowledge sources. Especially co-operative partnerships are regarded as effective means to gain access to personal knowledge that is not ubiquitously available because of limited personal mobility. Therefore, our investigation of the gatekeeper function is based on information about the inter-regional R&D cooperation activity of the actors in the fields of basic research, product innovation, and process innovation that was raised in the questionnaires.

Public research organizations show a pronounced propensity for inter-regional co-operation with respect to all three categories of innovation activity in our data (table 2). On average, public research actors' exhibit a higher propensity for inter-regional co-operation than private sector firms. It is remarkable that the majority of the research organizations show also relatively high involvement in regional co-operation activities so that their inter-regional orientation is not at the expense of intra-regional links. In the field of basic research, the universities exhibit the highest propensity for intra-regional co-operation as compared to the other groups of actors. The majority of the non-university public research organizations is not involved in regional R&D cooperation apart from their involvement in the innovation network under study. Similarly, their propensity for inter-regional co-operation turns out to be relatively low compared to the universities (table 2).

The manufacturing firms and the service firms in our sample clearly tend to ally with R&D cooperation partners that are located in the same region. Just 40% of the firms stated that they conduct R&D cooperation with partners external to their region (table 2). Although 60% of the firms undertake basic research in co-operation with regional partners, their propensity for inter-regional co-operation in the field of basic research is relatively low (22%). These findings confirm our supposition in section 2.3.

Table 2: Regional and inter-regional co-operation activity by different groups of actors (in %)

	Cooperation exists in the field of … (in % of organizations)						
	Basic research		Product innovation		Process innovation		Any
Actors in …	regional	inter-regional	regional	inter-regiona l	regional	Inter-regiona l	inter-regional coopera tion exist
Manufacturing firms	61.0	22.9	65.4	35.1	60.5	31.2	45.3
Service firms	68.5	22.3	66.9	29.2	64.6	28.5	38.0
Universities	71.7	60.4	58.5	44.3	52.8	36.8	67.6
Non-university public research organizations	60.8	54.9	41.2	37.3	41.2	39.2	64.7
Private research organizations	62.3	63.9	68.9	57.4	63.8	52.5	78.3

Public research organizations that are engaged in inter-regional R&D cooperation tend to transfer more knowledge to network partners than those that do not cooperate with R&D partners external to their region (figure 5). The knowledge transfer of the non-university research organizations increases significantly if they undertake inter-regional co-operations in product innovation (figure 6).[18] But even if one accounts for this “gatekeeper effect”, the universities are much more involved in the networks’ knowledge transfer activities than the non-university research organizations.

We find no statistical evidence in our data that the mere existence of inter-regional R&D cooperation of universities increases their extent of knowledge transfer to other network partners (figure 6). Correlation analyses reveal, however, that the universities’ extent of knowledge transfer is positively related to the frequency of R&D cooperation they undertake in product innovation and

[18] Statistically significant at the 10-percent level (mean values).

process innovation with partners external to their region (see figure 7).[19] The frequency of the universities' inter-regional co-operation in basic research has no influence on the extent of knowledge transfer to network partners.

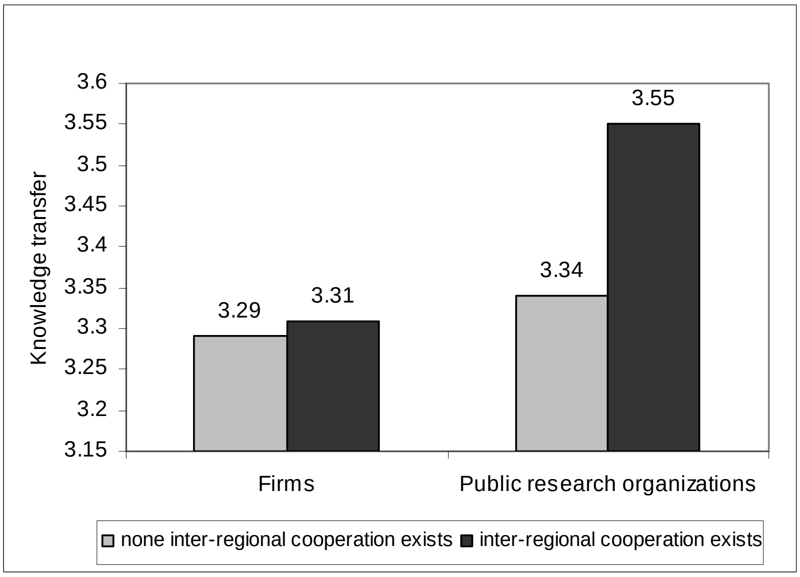

Figure 5: Inter-regional cooperation activity and knowledge transfer to network partners

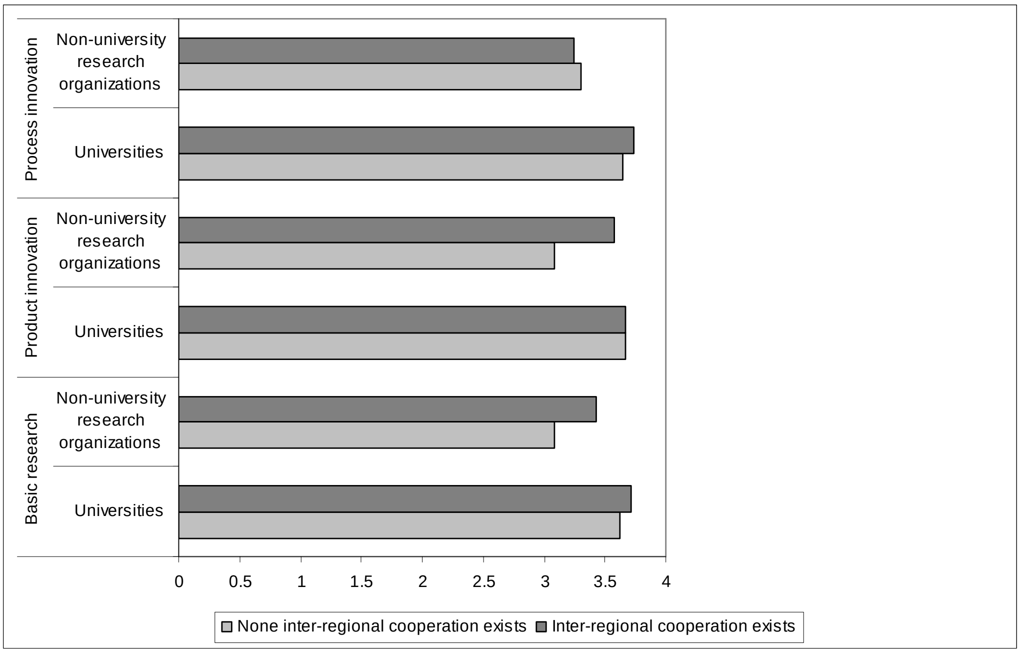

Figure 6: Subjects of inter-regional cooperation activities and knowledge transfer of public research organizations

[19] The correlation coefficient (Pearson) for product innovation is 0.474 (statistically significant at the 1-percent level) and for process innovation it is 0.337 (statistically significant at the 5-percent level).

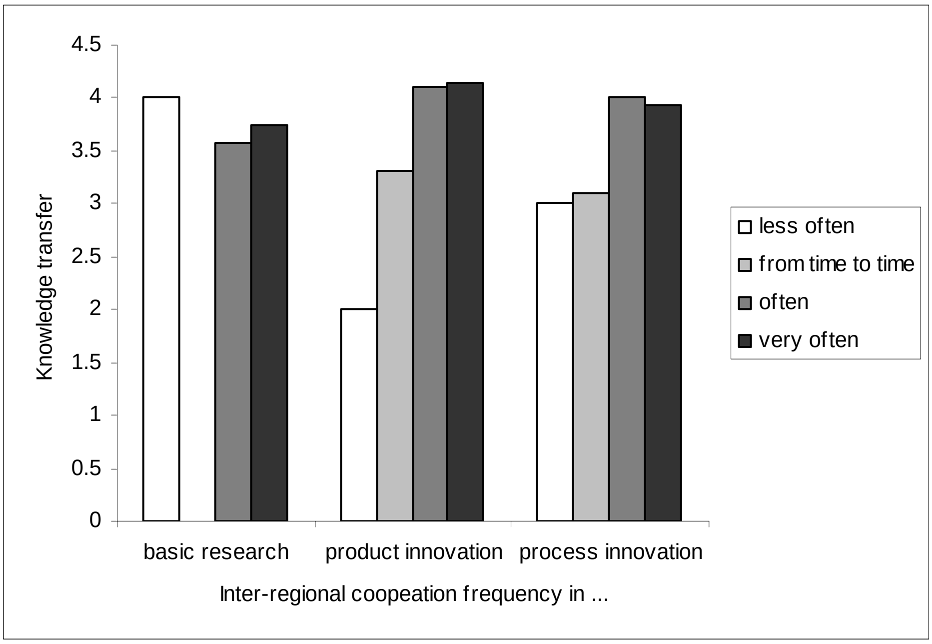

Figure 7: Universities' inter-regional cooperation frequency and the knowledge transfer to their network partners

With respect to the firms, we found no statistical relationship between the mere existence of inter-regional R&D cooperation activity and their knowledge transfer to network partners (figure 5). Analogous to the universities, the frequency of inter-regional co-operations is positively correlated to the extent of the firms' knowledge transfer.[20]

For the universities and non-university public research organizations, we found a pronounced positive relationship between the existence of inter-regional co-operation and the number of broker positions assumed in the innovation networks under study. Public research organizations that cooperate in R&D with partners external to the region hold on average 18 broker positions, whereas public research actors without inter-regional R&D cooperation activity assume only about 4 broker positions (figure 8). For the private firms, we find the opposite pattern: Those firms that co-operate in R&D with partners external to the region hold a lower number of broker positions in their regional network than

[20] The correlation coefficient (Pearson) is 0.243 (statistically significant at the 5-percent level).

those firms that have no such external co-operation in R&D (figure 8). This finding contradicts the common assumption that firms with interregional contacts often assume the role of a gatekeeper for the regional network.[21]

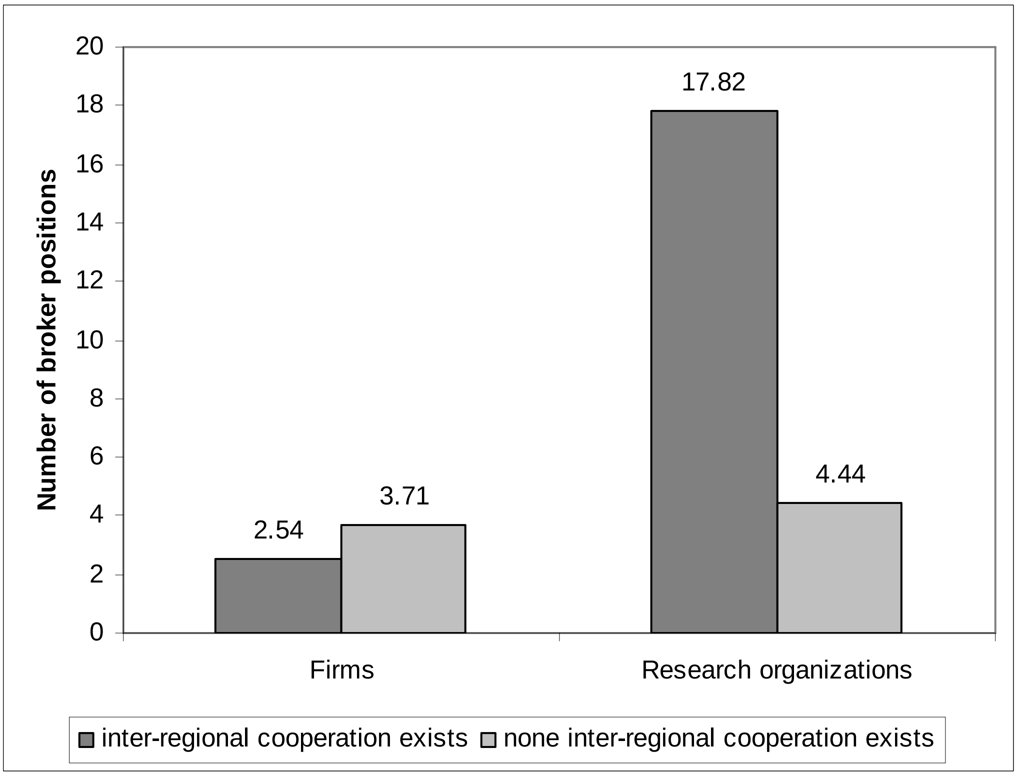

Figure 8: Inter-regional cooperation activity and the number of broker positions

5 Conclusions

Our analysis of knowledge exchange in regional innovation networks has clearly shown that public research organizations can be central players with respect to knowledge transfers to network partners. Several centrality measures for the position of public research organizations (e.g., degree, betweenness, and brokerage) support this conclusion. According to these indicators, public research organizations possess a significantly higher number of direct partners (degree) than the private sector firms. This result may well reflect the resource restrictions of SMEs that dominate the regions under study. Our investigations show that public research organizations tend to have broker positions in their

[21] The respective differences are, however, not statistically significant, which may be due to small case numbers.

network that enable them to transfer knowledge between the members of the network.

However, we found substantial differences within the public research sector with regard to the exchange of knowledge. Universities do not only transfer a higher extent of knowledge to their network partners than private sector firms, but they also transfer a significantly higher extent of knowledge than public non-university research organizations. Moreover, the extent of knowledge *absorbed* by the universities turns out to be significantly higher than that absorbed by the public non-university research organizations. In this regard, the universities outperform the non-university research organizations, which engage only relatively poorly in the knowledge exchange processes of their regional innovation networks regarding both the transfer of knowledge to and the absorption of knowledge from their network partners.

Based on the assumption that knowledge flows within a network do not exclusively result from direct ties but also are fostered by indirect links, we investigated the relation between broker positions and knowledge exchange. In this regard, we found striking differences. For the universities and for the manufacturing firms, the mere existence of a broker position as well as the number of broker positions held were positively related to the extent of knowledge transfer to network partners. Apparently, the broker positions of universities and manufacturing firms tend to transform into a broker function with social benefits for other organizations of the network. Moreover, universities as well as manufacturing firms that assume at least one broker position acquire a significantly higher extent of knowledge from their network partners. However, for the non-university public research organizations in broker positions, we neither found significantly higher degrees of knowledge absorption nor of knowledge transfer. Thus, the non-university public research organizations neither generate social benefits nor do they gain private benefits from the broker positions they assume. Since our data provide only information about the network structures at a certain point of time, we are unable to analyze the dynamics of the networks' evolution. Hence, we can make no clear statements if broker positions lead to higher degrees of knowledge exchange or if these positions emerge for actors that have a relatively high willingness and the ability to absorb and transfer knowledge. An answer to such questions would require longitudinal data.

Our results show that the universities are well linked to global knowledge sources by their inter-regional R&D partnerships. Their relatively high number of inter-regional *and* regional linkages enables them to fulfill a gatekeeper function that involves the absorption of globally dispersed knowledge and its transfer to regional innovation partners. Indeed, we found that the universities' frequency of inter-regional co-operation activity in product and process innovations is positively related to the extent of knowledge that is transferred to partners within the regional innovation network. Public non-university research organizations, however, although often more extensively involved in inter-regional R&D cooperation activities than the private sector firms, are not able to keep up with the inter-regional R&D cooperation propensity of the universities. Furthermore, non-university research organizations are considerably less involved in regional R&D cooperation activities compared to the universities. Based on the non-university research organizations' low transfer level, we found gatekeeper effects that result from the existence of inter-regional R&D cooperation activity in basic research or process innovations. In spite of these effects, the public non-university research organizations cannot accomplish the transfer level of the universities.

It could be argued that our results for the different types of organizations may be shaped by differences in their local conditions. While most universities are located in central cities, at least some of the non-university research organizations have locations in more remote places that are characterized by a small stock of innovative firms, which might partly explain their relatively poor transfer performance. However, as outlined above (section 3.3.1), the spatial dimension of our regional innovation networks is relatively small.

Summing up, we found compelling evidence that most of the universities in our sample make an enormous contribution to knowledge exchange activities within their regional network of innovation. There can be little doubt that universities can be key players in regional innovation systems if they are well connected to global pipelines and integrated in local buzz. Other organizations of the respective innovation system as well as innovation policy should integrate universities into networking initiatives. With respect to public non-university research organizations, regionalized innovation policy programs should address those researchers who already show frequent inter-regional R&D cooperation activity. Additionally, the weak local linkages of non-university research organizations, which basically exhibit transfer potential, as those in our sample, should be extended and strengthened.

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Appendix

Table A1: Definition of variables

Variable	*Description*	*Indicator*	*Measurement*
Information transfer	Information a network member has transferred to his partners	Did your network partner benefit from your information or suggestions?	5-point Likert-Scale (very few - very much)
Information absorption	Information a network member has received from his partners	Did you receive information, suggestions or other stimulation from your network partner(s)?	5-point Likert-Scale (very few - very much)
Knowledge transfer	Knowledge a network member has transferred to his partners	Did your network partner(s) benefit from your technical/professional assistance?	5-point Likert-Scale (very few - very much)
Knowledge absorption	Knowledge a network member has received from his partners	Did you receive technical/ professional assistance from your network partner(s)?	5-point Likert-Scale (very few - very much)
Degree/Ego-network	Degree/ego-network of an organization	Direct links/an organizations' (i) ego-network covers all network partners (organizations) that are linked *directly* to (i)	Number of direct links (partners)
Betweenness	Betweenness of an organization	An organization is located on the "shortest path" of two other organizations that are not linked directly	The frequency an organization (i) is located on the geodesic distance of two other organizations (jk) that are not linked directly; distance-based measure
Broker yes/no	Existence of a broker position	If an organization is located in at least one broker position	An organization (i) links to other organizations (jk) that are not linked directly
(n) number of broker positions	Number of broker positions	Number of broker positions an organization is located in	The frequency an organization (i) links to other organizations (jk), that are not linked directly (standardized for the size of the respective ego-network)
Inter-regional R&D cooperation activity	Existence of inter-regional R&D activities	Do you undertake R&D with partners external to the region (in basic research, product development, process development)?	Yes/no; aggregated to the organizational level (means)
Inter-regional R&D cooperation intensity	Inter-regional R&D cooperation frequency	How often do you undertake R&D with partners external to the region (in basic research, product development, process development)?	5-point Likert-Scale (not at all - very much); aggregated to the organizational level (means)

Table A2: Descriptive statistics

	Number of observations	*Mean*	*Minimum*	*Maximum*	*Standard deviation*	*Coefficient of Variation*
Information absorbed	334	3.54	1	5	1.01	1.01
Knowledge absorbed	334	3.51	1	5	1.07	1.15
Information transferred	336	3.46	1	5	0.85	0.73
Knowledge transferred	336	3.34	1	5	0.91	0.84
Degree/Ego-network size	338	3.41	0	29	2.98	8.88
Betweenness	338	5.41	0	76.38	12.21	149.00
Broker yes/no	338	0.68	0	1	0.467	0.22
Number of broker positions	338	6.75	0	367	29.69	881.50
(n) Number of broker positions (standardized for ego network size)	337	0.22	0	0.50	0.179	0.03
Inter-regional R&D cooperation activity	339	0.56	0	1	0.496	0.25
Inter-regional R&D cooperation frequency	334	3.31	1	5	0.94	0.88