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The impact of network structure on knowledge transfer: An application of social network analysis in the context of regional innovation networks

Michael Fritsch*

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Abstract

We analyze information and knowledge transfer in a sample of 16 German regional innovation networks with almost 300 firms and research organizations involved. The results indicate that strong ties are more beneficial for the exchange of knowledge and information than weak ties. Moreover, our results suggest that broker positions tend to be associated with social returns rather than with private benefits.

Keywords: Regional innovation networks, R&D-collaboration, knowledge exchange, social network analysis, strong ties, knowledge brokers

JEL Classification: D83, D85, L14, O32

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1 Introduction[1]

According to the resource-based view as well as to the knowledge-based view of the firm (Penrose 1959; Eisenhardt and Schoonhoven 1996; Grant 1996; Nonaka, Toyama et al. 2000), innovation and long run survival require access to external knowledge. Considerable parts of the respective knowledge are, however, not freely available or cannot be simply bought on the market. The main reason is that – in contrast to information – knowledge may be of a tacit nature (i.e., not codified), highly context specific, and may require certain capabilities in order to be absorbed. Integration into regional innovation networks can help firms to obtain this knowledge (e.g., Sternberg 2000; Fritsch 2001; Borgatti and Foster 2003). Empirical studies suggest that a transfer of knowledge may considerably benefit from embeddedness into networks and spatial proximity to network partners (Audretsch and Feldman 1996; Feldman 1999; Fritsch and Slavtchev 2007). However, the role of different types of actors in an innovation network as well as the benefits of strong versus weak network ties for such a transfer is largely unclear.

In this paper, we analyze the transfer of knowledge and information in 16 German regional innovation networks. We will particularly highlight the effect of the network structure, the position of an actor within the network, and the strength of the relationship. The data allow us to study the conditions that foster the transfer and the absorption of knowledge and information within the networks. In the following section (section 2), we review some key findings and hypotheses of earlier studies of regional innovation networks. Section 3 introduces the data and the measurement of variables used in the analysis. The results are presented and discussed in section 4. Section 5 concludes.

[1] We are greatly indebted to two anonymous referees for very helpful comments on earlier versions of this paper.

2 Information and knowledge exchange within regional networks of innovation

The advantage of the network form of organization as compared to market and hierarchy depends on the uncertainty of demand, the complexity of tasks, the asset specificity as well as the frequency of exchanges (Jones, Hesterly et al. 1997). Because partners in an innovation network tend to have closely related interests (Cowan, David et al, 2000), the chances of gaining valuable information and knowledge in such a network are relatively high. In addition to cognitive and technological proximity, social proximity within a network can be conducive to making information credible and interpretable (Uzzi 1996). It is often argued that ties which are embedded in a network tend to foster rapid and explicit feedback as well as joint problem-solving arrangements that may help the network members to generate new solutions and (re)combinations of ideas (Uzzi 1996). Furthermore, repeated interaction can shape the actors' mutual expectations towards trustful behavior, which may considerably improve the quality of exchange and the result of the interaction (Axelsson 1992, Lundvall 1993; Powell 1990; McEvily and Zaheer 2006; Daskalakis and Kauffeld-Monz 2007). Thus, the benefits of regional networks of innovation derive not only from reduced transaction costs and risk but also from access to valuable knowledge and information (Malmberg and Maskell 2002). This implies that embeddedness in a network may strengthen a firms' ability to be innovative.

The literature on regional innovation networks is closely related to the discussion about industrial districts, clusters (Feldman and Braunerhjelm 2006), and localized spillovers (e.g., Breschi and Lissoni 2001). An important difference between innovation networks and clusters or industrial districts is that firms located in a cluster may benefit from other firms or from public research institutions even without having any explicit relationship to these actors, e.g., by 'pure' spatial knowledge spillovers. However, innovation networks are based on direct relations, and the exchange processes within networks are critically affected by the very nature of knowledge and information. Knowledge and information differ considerably with regard to their sensitivity to spatial distance to a communication partner. While the costs of an information transfer tend to be largely independent of spatial distance, an exchange of knowledge often requires face-to-face contacts, especially if the knowledge is not codified but tacit (Polanyi 1967). Tacit knowledge is bound to the person that possesses the knowledge and a transfer of this knowledge requires personal face-to-face contact (Teece 1981; von Hippel 1994; Asheim and Isaken 2002). For this reason, the spatial proximity as such is not important for the transfer of knowledge, but rather the factual existence of network ties within spatial proximity (Lissoni 2001).

A prominent hypothesis put forward by Granovetter (1973, 1985, 2005) is based on the idea that 'strong ties' characterize a dense network of actors who are mutually connected to each other (Granovetter 1973). Since the actors of this (sub)cluster tend to interact frequently, a high share of the information circulating in this social system is redundant. Granovetter posits that *new* information is mainly obtained through relationships to actors who are not members of the closely connected part of the network, the 'weak ties', rather than through close relationship (strong ties). However, adopting this argument in the context of innovation activity may be problematic for several reasons. First, Granovetter mainly discusses the effect of social structures on issues such as information about job offerings and new technologies and does not consider the generation of knowledge that is in the core of innovation activity (Granovetter 1973, 1985, 2005). In such a context, the gathering of information through weak ties may be more important than trust and openness of exchange which is the domain of strong ties. Obviously, whether strong or weak ties turn out to be more favorable depends on the characteristics of the subject that has to be transferred. While strong ties may be better suited for an exchange of complex knowledge, weak ties could be more beneficial for searching for information (Hansen 1999).

A second caveat against transferring Granovetter's argument to the context of innovation networks is that his original analysis (Granovetter 1973) only refers to dyadic relationships and not to entire networks. Thirdly, as stated by Burt (1992), information benefits are expected to travel over all bridges, strong or weak. Burt argues that not the strength of a tie can be regarded as the main reason for access to new information, but rather non-redundant relations and the position as a network-broker, i.e., an actor who is bridging a structural hole.

The concept of structural holes considers network ties as a means of linking agents of separate network segments by bridging ties. A bridging actor assumes a broker position. He makes a connection between non-redundant sources of knowledge and information. Non-redundant contacts that result from bridging structural holes provide access to information that is rather additive than overlapping because the segments of the network on each sides of the structural hole differ with regard to the underlying knowledge and information. Therefore, bridging a structural hole creates an advantage for the broker (Burt 1992). Analyses by McEvily and Zaheer (1999) indicate that non-redundancy in a firm's network may explain the acquisition of capabilities. Accordingly, the systematic development of broker positions can be regarded as a means of managing knowledge flows within firms (Hoegl und Schulze 2005).

An argument against the benefits of bridging structural holes states that closed networks produce higher rents for its members in comparison to open networks due to a higher level of trust and cohesion within a closed group (Gudmundsson and Lechner 2006). Empirical research (Gudmundsson and Lechner 2006; Kadushin 2002) indicates that cohesion and brokerage are not necessarily in conflict but can both be combined in a productive manner. Therefore, structural holes can be regarded as a source of value added while network cohesion may be essential for realizing the value buried in a hole (Burt 2001). A bridge that connects actors which are not otherwise linked can be considered social capital (Burt 2001).

3 Hypotheses, data, and measurement

3.1 Hypotheses

Our empirical study of network relationships is focused on the following three hypotheses.

(1) *In regional networks of innovation, the benefits of strong ties are larger than the benefits that result from weak ties.*

(2) *Network cohesion (the overall connectedness of the network members) has a positive effect on the transfer of information and knowledge.*

(3) Broker positions produce considerable private and social returns.

In contrast to Granovetter's hypothesis concerning the 'strength of weak ties', we posit that in the context of regional innovation networks weak ties are not conducive to the transfer of knowledge and information (hypothesis 1). On the contrary, we assume that especially strong ties enable the exchange of information and knowledge when interactions and outcomes are accompanied by a high degree of risk and uncertainty and when knowledge with tacit dimensions is involved. It may be argued that this hypothesis holds particularly for knowledge but does not pertain to the exchange of information. However, beyond the 'tacit knowledge' argument, there is another reason for the advantage of strong ties. In order to be able to perform an information selection function for a network partner (e.g., filtering the relevant information), an actor has to be aware of the needs and the deficiencies of the potential receiver of information. Moreover, firms typically do not disclose sensitive information without having a strong tie to the respective actor. Therefore, the information selection function works better if it is based on strong ties.

We expect that network cohesion is conducive to the transfer of knowledge and information (hypothesis 2) for two reasons. First, network cohesion makes the transfer of knowledge and information easier due to more direct links between the parties involved. Information and knowledge is more accurately and timely transmitted in networks where many actors are directly connected to each other, particularly, if appropriate interfaces between the partners are established. Transfer over a longer distance is more complicated, may take more time, and there is a higher probability of mistakes and distortions (Cross, Parker et al. 2002). Thus, network cohesion should result in a higher level and higher accuracy of information and knowledge transferred. Second, a high level of network cohesion is conducive to the emergence of reputation effects. This implies that any kind of information pathology (Scholl 1999) such as closure, distortion, or delay as well as unintended disclosure of knowledge is more likely to be noticed and sanctioned in a dense network than in networks which are more fragmented. If reputation effects are at work, every actor has strong incentives to transfer information and knowledge fully, accurately, and timely as well as to handle business secrets with the appropriate amount of care.

The benefits that result from bridging a structural hole by a broker may be diverse. Among these benefits is the reduction of information asymmetries. Nooteboom (2003) points out that problems of „asymmetric information“ can be reduced if there are bridging or mediating agents available. Brokers may act as arbitrators of simple contracts and can help to alleviate misunderstandings. If a broker has a good reputation within the network, this may help to control the risk of spillovers and mediate the building and maintenance of trust (Zucker 1986; Shapiro 1987; Nooteboom 2003). Clearly, bridging a structural hole may entail benefits for the respective actor as well as for the sub-networks that are connected. Thus, we expect social returns as well as private benefits resulting from brokerage (hypothesis 3).

3.2 Data

Our analysis is based on detailed information about 16 East German regional innovation networks that were initiated in 1999. This implies that the networks in our sample are at a relatively early stage of development. The networks have been selected in the promotion policy program “InnoRegio”, which aimed to improve regional innovation systems (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 institutes (Eickelpasch, Kauffeld et al. 2002a, 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. For this reason, the networks should be well comparable. Differences between the networks particularly concern the industries and technologies[2] involved as well as the number and the character of organizations (see table A2 in the Appendix). About 60 percent of the organizations were private firms. Universities consist of 10 percent and about 16 percent of the actors were public or private non-university research institutes. About 20 percent 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 percent have less than 20 employees and only 10 percent have more than 100 employees. The service sector firms, which make about 40 percent 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 and Kauffeld 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 and Kauffeld et al. 2002b). For this reason, there is a certain sample selection bias with regard to innovation attitudes, innovative capacities as well as expectations about future growth.

3.3 Measurement

3.3.1 Network construction

The data were gathered by postal questionnaires in the year 2004 that resulted in a quite high response rate of about 80 percent. Each actor of a network was asked to name his most important partner(s) within the network. Organizations which 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 actor as one of their “most

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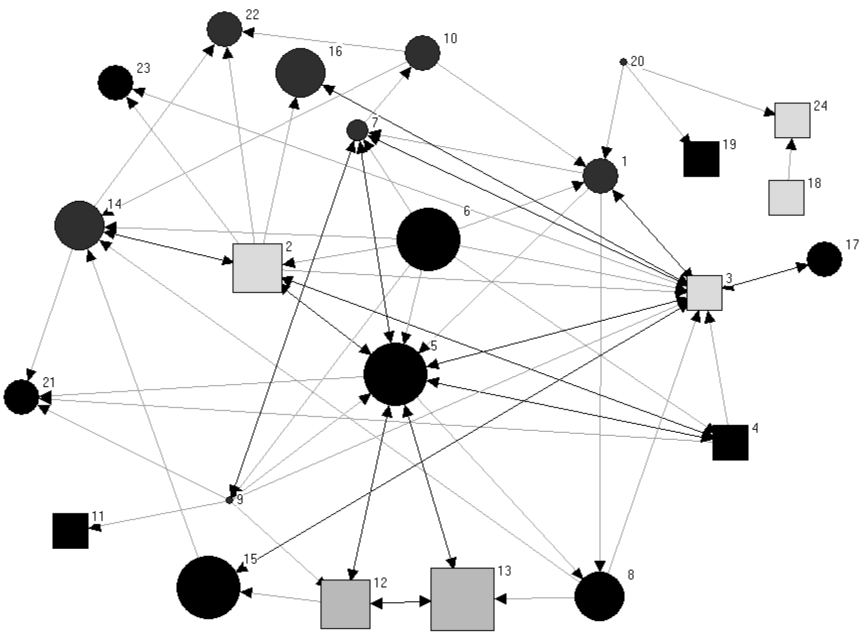
[2] E.g., bio-technology, medical technology, automotive, innovative textiles, phytopharma,

important partners”. In this manner, we tried to capture the complete network. On average, actors named three partners, in most cases members of their actual R&D-co-operations, as “most important partners”.[3] On the basis of these links we generated a network matrix for each network. These matrices have been transformed into graphical expositions that allow for identify reciprocal and non-reciprocal links. We assume that knowledge and information is transferred along these links. As an example, figure 1 shows a network graph for one of the innovation networks in our sample. The arrowheads indicate the direction of the knowledge flows. A considerable portion of the network links (about 60 percent) was non-reciprocal. There are, however, considerable differences between the networks with respect to the degree of reciprocity, which ranges from 20 percent up to 80 percent (see table A2 in the Appendix).



Notes: O = firm; □ = public research; the numbers identify the individual actors; bold arrow = reciprocal tie; semi-bold arrow = non-reciprocal link; arrowheads = direction of knowledge-flow; symbol size = extent of knowledge absorption.

Fig. 1 Example of a network graph

health industry, musical instruments

[3] 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, partners involved. However, the subsidies are basically restricted to the early stage of innovation.

3.3.2 Dependent variables

With regard to the different types and dimensions of knowledge (Nonaka and Takeuchi 1995; Cowan, David et al. 2000), our analysis focuses mainly on the technological know-how exchanged between actors, measured by “the extent of technological support” provided or received (see table A1 in the Appendix). However, there also may be some degree of “know-what” (declaratory / factual knowledge) as well as “know-why” (scientific knowledge) included in these flows. We have strong indication from in-depth interviews with selected network members that a considerable part of the transferred knowledge is of a “tacit nature”.

We measured the exchange of information as “the extent of information and suggestions” provided or received. In-depth interviews with network actors have shown that this information may refer to market conditions, competences of potential partners as well as to management practices. In comparison to knowledge, such types of information should be subject to transfer barriers resulting from tacitness, high context specificity or inappropriate ‘codebooks to a lesser extent and can be expected to travel easier along the network links.

We constructed four indicators for the exchange of information and knowledge that were the dependent variables in our regressions:

(1) The extent of information transferred to network partners.

(2) The extent of knowledge transferred to network partners.

(3) The extent of information absorbed from network partners.

(4) The extent of knowledge absorbed from network partners.

The extent has been measured on a 5-point Likert scale ranging from “very few” to “very much” (see table A1 in the Appendix).

3.3.3 Independent variables

The independent variables refer to four spheres of influence (figure 2). These are:

(a) The characteristics of the entire network (network cohesion, heterogeneity of competences).

(b) The characteristics of each actor's ego-network (density, tie strength).

(c) The positions of an actor in his ego-network (e.g., broker position).

(d) The individual characteristics of an actor (firm size, experience with R&D-cooperation).

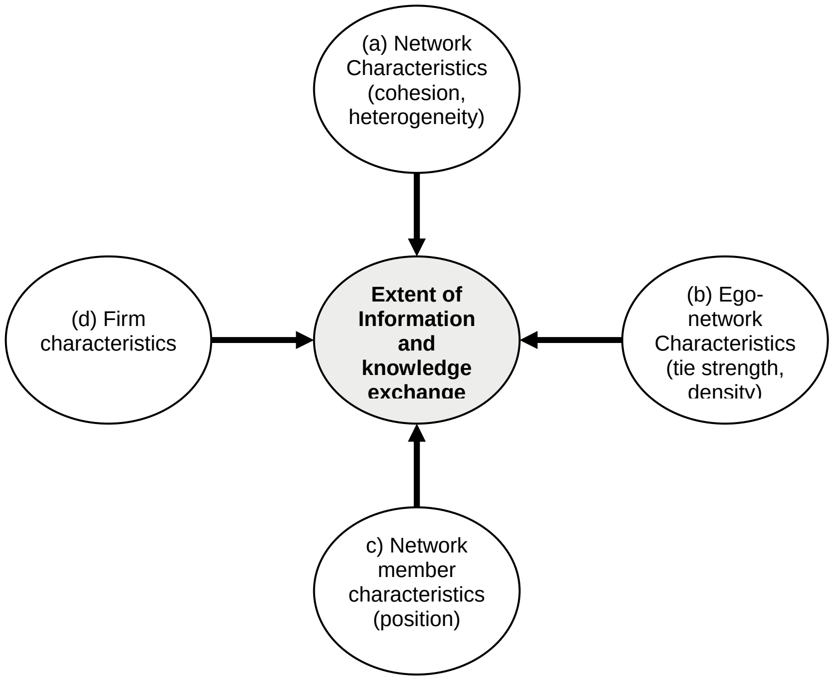


Fig. 2 Determinants of information-flow and knowledge-flow by different areas of influence

(a) With respect to the characteristics of the network as a whole, we refer to cohesion of the network and to the heterogeneity of competences of the actors that form a network. Cohesion indicates the degree of redundancy of relationships within a network (Burt 2001). A 100 percent degree of network cohesion would be attained if all actors of a network were directly linked to each other. On average, the networks under study exhibit a 29 percent degree of cohesion. Network studies often argue that a non-redundant structure (i.e., a low degree of cohesion) is advantageous for the flow of information and knowledge within a network. Cohesion also may be a key driver of collaborative innovation because it facilitates trust building and the development of common norms, such as modes of conduct. According to the latter argument, we expect a positive impact of cohesion on information and knowledge exchanges. The degree of cohesion is calculated as the number of realized ties divided by the number of possible ties.[4]

In line with the Schumpeterian tradition, we assume that entrepreneurial opportunities may occur by (re)combinations of different, previously unconnected resources and, therefore, refer to the variety of knowledge bases, competences, and resources. Thus, we suppose that heterogeneity of competences constitutes a more meaningful indicator rather than the more structural concept of (non-)redundancy. However, our measurement of heterogeneity does not assume that the more actors 'on board' means the higher the diversity will be. Instead of the mere size of a network, we draw on information about the scope of the network members' competencies that has been elicited in the postal questionnaire. Heterogeneity of competences is measured on a 5-point Likert scale ranging from "not at all" to "completely heterogeneous".

(b) Whereas the network characteristics refer to the entire network and, therefore, involve direct as well as indirect ties, the ego-network of an actor contains only those network members to which the respective actor is linked directly. Following McEvily and Zaheer (1999), we assume that the frequency of interaction – as employed by Granovetter (1973) – is only a rather rough measure of tie strength. In the context of innovation activities, it would be more adequate to refer to the scope (multiplicity) and the intensity of the relationship. Hence, we employ the "degree of trust between direct network partner(s)" as an indicator of tie strength. This degree of trust is measured on a 5-point Likert scale ranging from "not at all" to "completely trusting". We also account for the density of an ego-

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[4] In our network example (figure 1), the degree of cohesion amounts to 20 percent (54 realized ties divided by 276 possible ties).

network; thereby, expecting a positive relationship between the ego-network density and the extent to which information or knowledge is exchanged. The density of an ego-network is measured as its number of factual ties divided by the number of possible ties.[5]

(c) A further factor that may be important for the exchange of information and knowledge is the specific position of network actors in their ego-network. We focus here on broker positions of an actor. According to Gould and Fernandez (1989) four types of brokerage positions may be distinguished from the perspective of an actor who belongs to the group of the private firms. The four types of brokerage are the following: first, brokerage between two private sector firms (coordinator); second, linking two members of the public research sector (consultant); third, relating a private firm and a public research organization, whereas “flows” occur from the former to the latter (representative); fourth, brokerage between a private firm and a public research organization, whereas “flows” occur from public research to private businesses (gatekeeper). Such a distinction may, however, be rather arbitrary because actors may, for example, simultaneously assume the role of a “gatekeeper” *and* the role of a “representative” because the exchange of knowledge and information is of a reciprocal nature. For this reason, we do not follow this distinction but assign a broker function to each of these positions, i.e., whenever an actor indirectly connects two other actors of his ego-network which are not otherwise directly linked to each other. The number of these brokerage positions indicates the degree to which an actor is bridging structural holes in his ego-network.[6] Hence, we strongly separate the structural holes measure from the tie strength. In order to avoid size effects of this

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[5] According to McEvily and Zaheer (1999), we do not consider density as an indicator of tie strength because even a dense network may have many links that are not really resilient. An important intervening variable in this respect is the size of the network. Because establishing and maintaining strong ties require specific investments, large networks tend to be characterized by low densities while they can, nevertheless, involve rather strong ties. Thus, from our point of view, ego-network density comes closer to the concept of network cohesion than to tie strength.

[6] For example, in the network graph above (figure 1), the actor number three (a university) takes on a broker position with regard to his ego-network 37 times whereas the actor number eight (a manufacturing firm) takes on a broker position eight times.

measurement, we normalized the number of broker roles by dividing it by the number of potential ties in an actors' ego-network.[7]

(d) Finally we control for firm size (classified into five categories)[8] as well as for absorptive capacity. Following Simonin (2004), we use the "former existence of R&D with partners external to the firm" to differentiate between those actors that are well trained in exploiting external resources and those that have only recently started to build up resources and competences for acquiring knowledge from beyond the boundaries of their organization.

4 Results

Our analysis clearly shows a high level of information and knowledge exchange among the members of the networks in our sample (figure 3). The group of actors that benefited the most from the absorption of knowledge is the manufacturing firms followed by the private research organizations. The main sources of knowledge were the private research organizations and the service firms. The differences among the other groups of actors with regard to the degree of information absorbed (public research organizations, service firms, universities and associate research institutes ("An-Institute") are relatively small. It is, however, remarkable that the respective value is relatively low for the public research organizations. With regard to information transferred, we again find the universities in first place followed by the service firms, the public research organizations, and then the other three types of actors. 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. Non-university public research organizations

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[7] It could be argued that it would be more adequate to apply betweenness-centrality as a measure for brokerage. Betweenness-centrality refers to the entire network and counts how often an actor is located at the shortest path (geodesic distance) of all pairs of actors who are not linked directly. It indicates an actor's possibilities to control the relation between two other network actors. We do not apply betweenness-centrality because this measure is not adequate for transfers of highly specific tacit knowledge which does not travel "long distances" in terms of nodes that have to be crossed.

[8] Classification by number of employees: 1-10; 11-50; 51-100; 101–250; 250 plus.

as well as the associate research institutes (An-Institute) transferred considerable amounts of information to their partners but cannot be regarded as a central source of knowledge. The universities and the manufacturing firms seem to have benefited the most from the exchange of information and knowledge within the networks. A comparison of the weights for knowledge/information absorbed and knowledge/information transferred suggests that the manufacturing firms drew the largest net-benefit from their participation in the networks.

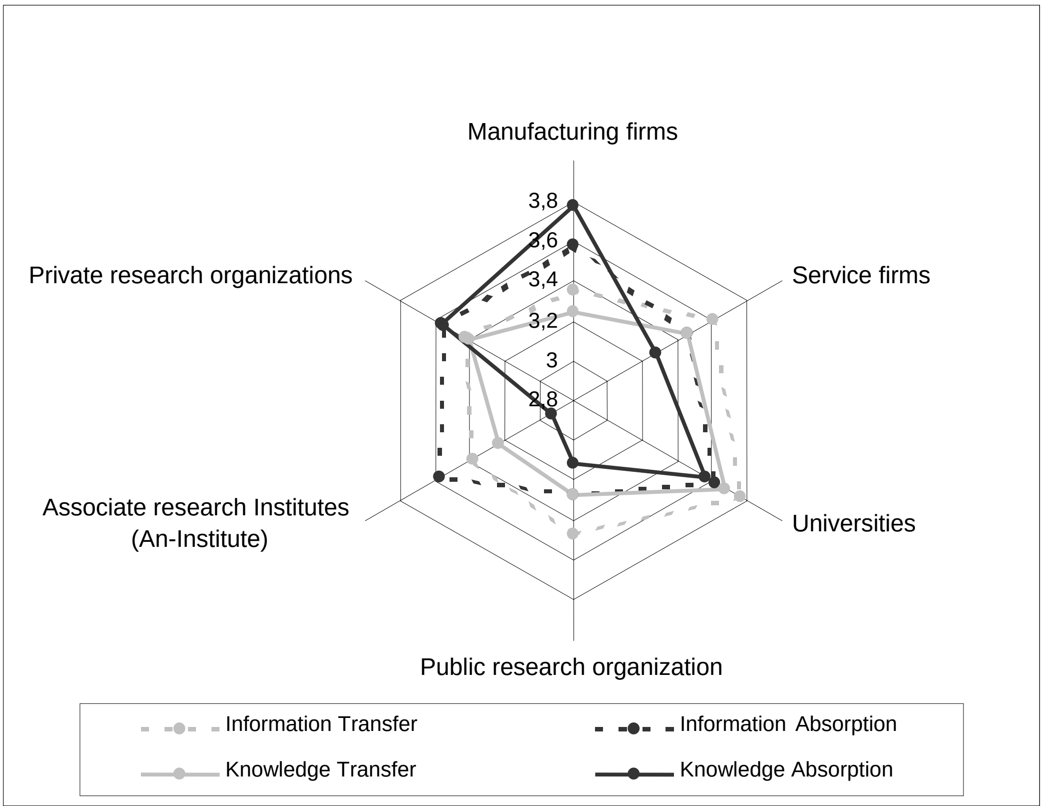

Fig. 3 Transfer and absorption of information and knowledge by groups of actors

The further analyses focus on the transfer of information and knowledge into the private sector, i.e., to the manufacturing and the service firms in the sample.[9] 194 private firms took part in the inquiry. For some of the firms we obtained multiple responses because they conducted more than one collaborative R&D-project in their network.[10]

[9] Initial comparative analyses confirm our assumption that with regard to different groups of regional innovation systems (private sector, public science) the mechanisms that are positively related to exchange processes vary due to their relative importance.

[10] There were 322 responses from private sector firms that have been aggregated to the firm level. All measures for the network properties (e.g., network cohesion, ego-network

Contrary to Granovetter's strength of weak ties-hypothesis, we found the strong ties to be particularly important with regard to the exchange of information and knowledge (table 1, models 1 - 4). The estimated coefficients also indicate a positive relationship between network cohesion (overall connectedness of network members) and the extent of information exchanged (models 1 and 2). The results for the knowledge exchange (models 3 and 4) are more ambiguous. Whereas a high degree of cohesiveness seems to be conducive to knowledge transfers to network partners (model 3), many of the partners obviously were not interested in its absorption as is indicated by the insignificant coefficient for the relationship between network cohesion and knowledge absorption (model 4). Thus, a certain amount of knowledge conveyed to network members and fostered by a highly cohesive network structure is apparently not highly valued by the network partners.

Table 1 Regression analyses

	Dependent Variables (models)							
	Information exchange				Knowledge exchange			
Independent Variables	Transfer (1)		Absorption (2)		Transfer (3)		Absorption (4)	
	Coef-fícient	t-value	Coeffi-cient	t-value	Coeffi-cient	t-value	Coeffi-cient	t-value
Constant	2.30***	6.136	1,082**	2.224	1,920***	4.766	1,056**	2.045
Tie strength	.168**	2.336	.249***	3.433	.135*	1.903	.285***	3.961
Ego-network density	.151*	1.934	.096	1.219	.088	1.146	.139*	1.770
Network cohesion	.176**	2.482	.129*	1.807	.176**	2.518	.015	.214
Heterogeneity	-.116	-1.627	.112	1.558	.039	.549	.085	1.185
nBroker	.175**	2.250	.063	.804	.112	1.458	.048	.621
R&D cooperation experience	.280***	4.079	.149**	2.148	.308***	4.554	.123*	1.792
Firm size	-.101	-1.469	-.023	-.323	-.179***	-2.635	.091	1.314
Number of observations	194		192		194		192	
R^2 adjusted	0.135		0.122		0.160		0.136	

An additional type of network characteristic that may influence the exchange of information and knowledge is the heterogeneity of

density, brokerage) include also the other types of actors such as universities and non-university public research institutions.

competences of the network partners. Heterogeneity can be regarded as an extension of the more structural concept of non-redundancy. It refers to innovation opportunities that result from a (re)combination of different competences. We suppose that heterogeneity of competences serves as a better indicator than (non-)redundancy. In the literature, it is quite frequently supposed that heterogeneity in terms of divergence of knowledge, competences, resources, and problem solving capabilities is positively related to the exploration of opportunities (Gilsing and Nooteboom 2006). The respective ties stimulate the implementation of new routines, may expand the organizational boundaries into previously uncharted markets, and can be regarded as conduits of second-order learning processes (Bateson 1972; March 1991; Levinthal and March 1993). However, exploitation refers to the refinement and extension of current routines that strengthen the economic activities in known knowledge domains and gives rise to first-order learning (Bateson 1972; March 1991). According to our estimates, the extent of heterogeneity of competences among network partners has no statistically significant impact on the firms' knowledge and information exchange (table 1, models 1 – 4). Following March's strict differentiation between exploration and exploitation (March 1991), this result indicates that the firms involved in the networks under study obviously tend to be more interested in exploitation than in exploration.[11]

We found that the actors which assume broker positions are not able to gain particular advantages in terms of the absorption of information or knowledge (table 1, models 2 and 4). But as the results indicate, broker positions enhance the extent of information transferred to network partners (model 1). All in all, our results indicate that there are no private returns resulting from the number of broker roles an actor assumes. However, we find strong evidence that brokering organizations are generating social returns, especially in terms of additional information transferred to their network partners.

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[11] Interestingly, with regard to network members belonging to public science, we found a significantly positive relationship between heterogeneity of competences within a certain network and knowledge acquisition.

Firm size is significant only with respect to the transfer of knowledge and not the transfer of information. Surprisingly, the smaller the firm is, leads to more knowledge being transferred to network partners. Obviously, smaller firms were more engaged in the transfer processes within the network. We find that absorptive capacity in terms of experience in conducting R&D with partners is more important for the absorption of external information and knowledge than firm size.

5 Discussion and conclusions

Our analysis showed that embeddedness within an innovation network is positively related to an inter-organizational exchange of knowledge and information. We found that particularly strong ties are important prerequisites for such a division of information and knowledge. In interpreting the result one should, however, keep in mind that embeddedness in strong ties may also lead to lock-in (Grabher, 1993) or entropic death (Camagni, 1991) and can well have negative effects on innovation performance. Such effects were, however, unlikely to occur in our study because the networks in our sample were collected at an early stage of development. Firms can obtain the optimal balance between essential tie strength and regional embeddedness, on the one hand, and the avoidance of cognitive lock-in, on the other hand, by searching for heterogeneous knowledge outside their regional network. It would, therefore, be rather interesting to perform the analysis for older, well-established networks or for the networks in our sample at a later stage in their development.

Hite and Hesterly (2001) suggest that firms at an early stage of development gain higher benefits from a more cohesive network whereas they exploit network benefits that derive from bridging structural holes when they arrive at more advanced stages of their development. This, however, cannot fully explain why the firms in our sample do not benefit from their brokering positions. Thus, more investigations should be dedicated to the conditions that enable the exploitation of benefits resulting from brokerage.

The differences in the results between transfer and absorption as well as between knowledge and information showed that these distinctions are fruitful and important. Further research should investigate different types of knowledge and information. Moreover, it appears rather promising to analyze the role of different types of actors (universities, other public research institutions, small and large firms) in innovation networks in more detail. Regarding the design of respective policy measures, it is rather important to learn more about the ways in which knowledge and information in networks is transferred between the actors and how the strong ties are formed.

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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)
Tie strength	Trust of a network member (A) towards his direct/immediate network partners	Is there fairness and trust between the network partners?	5-point Likert-Scale (not at all - very much)
Ego-network density	Density of a network member's ego-network.	An actor's (A) ego-network is covering all network partners that are linked *directly* to A	Number of realized ties divided by the number of potential ties
Network cohesion	Degree of network cohesion	Based on geodesic distances (the length of the shortest path that is connecting two nodes) between the actors.	Based on mean geodesic distances of all actors to each other
Heterogeneity	Diversity of competences/resources within a network	There is a wide range of partners with complementary competences n the network	5-point Likert-Scale (not at all - very much)
nBroker	Information and knowledge broker	Number of broker functions that an actor assumes.	Standardized for the size of the respective ego-network
R&D-cooperation experience	Existence of partners in R&D external to the organization	Has your firm undertaken R&D with partners external to the firm in the last two years?	Yes/No
Firm size	Size of the firm	Number of employees in 2003	Ranked into five classes

Table A2: Descriptive statistics

	Number of observations	Mean	Minimum	Maximum	Standard deviation	Coefficient of Variation
Number of participating organizations per network (network size)	231	27.62	7.00	51.00	13.197	47.78
Information absorbed	230	3.52	1.00	5.00	1.059	30.08
Knowledge absorbed	229	3.57	1.00	5.00	1.087	30.44
Information transferred	232	3.40	1.00	5.00	0.848	24.94
Knowledge transferred	232	3.29	1.00	5.00	0.917	27.87
Tie strength	214	3.98	1.00	5.00	0.818	20.55
Ego-network size	230	2.90	0.00	9.00	1.764	60.82
Ego-network density	229	41.44	0.00	100.00	36.232	87.43
Number of broker functions	230	3.15	0.00	94.00	7.935	251.90
Network cohesion	232	0.29	0.19	0.52	0.076	26.20
Heterogeneity of competences	213	3.96	1.00	5.00	0.921	23.25
Reciprocity	232	0.41	0.20	0.82	0.128	31.21
Number of employees	221	56.40	1.00	1250.00	109.734	194.56
R&D-cooperation experience	233	0.57	0.00	1.00	0.492	86.31

Table A3: Correlation of variables

	Information transferred	Information absorbed	Knowledge transferred	Knowledge absorbed	Tie strength	Ego-network density	Network cohesion	Heterogeneity	nBroker	R&D-cooperation experience	Firm size
Information transferred	1										
Information absorbed	.223**	1									
Knowledge transferred	.772**	.136	1								
Knowledge absorbed	.161*	.618**	.132	1							
Tie strength	.149*	.281**	.140	.337**	1						
Ego-network density	.097	.103	.071	.142*	.040	1					
Network cohesion	.185*	.141	.184*	.043	-.112	.132	1				
Hetero-geneity	.022	.227**	.165*	.195**	.263**	.075	.109	1			
nBroker	.098	.033	.062	.000	.076	- 482**	.030	.016	1		
R&D-cooperation experience.	.287**	.199**	.337**	.166*	.074	.018	.112	.179*	- 051	1	
Firm size	-0.20	.050	-.104	.149*	.143*	.048	.180*	.007	.013	.054	1