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Structural Characteristics of Knowledge Exchange in Innovation Networks

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Abstract

While there is a large pool of assured knowledge on various general dimensions of structures and dynamics of innovation networks, there are basic structural features that should attain more attention in future network research. Our contribution concentrates on three key structural characteristics: (i) kind of actors, (ii) contexts and (inter-) organizational environments of networks and (iii) modes and contents of knowledge exchange. We discuss the role of these structural characteristics at the example of research material drawn from an accompanying evaluation of the German 'Leading-Edge Clusters Competition'. Major results are: Innovation network actors present themselves in a highly heterogeneous manner; the relevant spectrum reaches from utmost complex organizations to single individuals. Networks are embedded in different sectoral, organizational and situational contexts. In many cases, already the delimitation of the relevant network is a challenge for innovation researchers. Knowledge exchange uses different channels and presents itself as context-dependent combination of formal and tacit elements, of (relative) openness and restraint of the acting individuals and organizations.

Keywords: Innovation Networks; Actors; Knowledge Exchange; Cluster Organization; Cluster Policy

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1 Introduction

Inter-organizational innovation networks developed into a favourite research object of economic and social innovation studies in the last decades (Cantner and Graf 2011, Powell and Gianella 2010, Powell and Grodal 2005, Smith-Doerr and Powell 2005). Empirical studies show that innovation network relationships may help firms to improve their economic and innovative performance as expressed, for instance, in sales and returns or the number of patents granted. Such evidence could be given especially for science-based technology fields such as biotechnology (e.g. Powell et al. 1999).

The increasing knowledge on the mainly positive role of network relations in research and innovation processes has inspired innovation policy to support the development of networks based on the expectation that this would spur innovations and, especially, help to bridge the gap between academia and enterprises in research-intensive technology fields. Though hard evidence on the effects of network and cluster policies is rather limited so far (for the state of knowledge on cluster policy effects see Uyarra, Ramlogan 2012), the respective policy concepts were widely applied by policy makers in old and new industrial countries. The incipient network and cluster 'craze' (Cowan, Jonard 2004: 1571) is reflected in an increasing number of research and innovation policy programmes that foster networks and cooperations of different kinds. Examples are collaborative R&D projects as well as long-term cooperation platforms like cluster initiatives or on campus cooperation models.

Network promotion aims at fostering the knowledge exchange between network actors whereby the transfer of knowledge from academic institutions to firms is a core target of many relevant programmes. The terms 'knowledge exchange' and 'knowledge transfer' are often used as synonyms in the relevant literature. Some authors prefer the term 'knowledge exchange' (Cantner and Graf 2011), others favour 'knowledge transfer' (Powell and Grodal 2005: 74-77) for designating any transmission of knowledge between two actors. In our discussion, we use the term 'knowledge transfer' for management and political contexts such as the transfer of university-based knowledge to SMEs addressed by network promotion programmes. But the distinction also has an important aspect with respect to contents: The wider concept of knowledge exchange subsumes any transmission of knowledge between two agents regardless of the state of knowledge conveyed and the degree of awareness of this transmission on the part of the actors involved. Knowledge exchange within innovation networks nearly always takes place based on reciprocal relations, but (full or partial) reciprocity is not a precondition for the classification of a transaction as 'knowledge exchange'.

The assessment of the ability of network and cluster policies to foster knowledge exchange and the innovative capacities of the actors presupposes precise information on their effect generating mechanisms and probable impacts, on their possibilities and limits. It has been argued, that within the still relatively young discipline of network research knowledge about the functionalities and effects of networks is still limited (Powell and

Grodal 2005: 79). As Cantner and Graf (2011: 390) observe, the field of innovation network studies had originally started from an interdisciplinary research effort of economists, sociologists and management researchers, but has evolved subsequently more and more into a research area dominated by the micro perspectives of business and management studies.

At this backdrop, one challenge for researchers would be to reintegrate the diverse research strands and to approach the network issues from a more interdisciplinary, system-oriented point of view. Such approaches could on the one side overcome the individualistic view of management-oriented network research and, on the other side, enrich the field of model-based network studies. Consequently, Smith-Doerr/Powell state that "much remains to be done to integrate quantitative and qualitative studies of networks" (2005: 394), a claim which seems still relevant presently. This is all the more evident by the fact that many results on the innovative success of networking actors seem to be context dependent (Cantner, Graf 2011: 390). As the authors notice, this context comprises, among others, the type of relations under examination, the type of knowledge exchanges, and the tasks performed by the collaborating units.

With our contribution we would like to draw the reader's attention to three (selected) central aspects of knowledge exchange in innovation networks of actor, kind/context, contents, and thus make a contribution to fill the gap between qualitative and quantitative innovation network research. The discussed topics are:

- the diversity of actors operating in innovation networks,
- the role of highly differing sectoral, social, organizational and inter-organizational contexts in which these networks operate, and
- the differing channels and contents of knowledge exchange within these networks.

Obviously, all of these topics have been discussed repeatedly in publications that present results of empirical or theoretical innovation network research. To cite some examples, the context and contents of knowledge exchange was analysed by Thagard (2005) for a special research environment (humanities) by looking at collaborative university-based academic research. Cowan et al. (2000) made implications of the tacitness of knowledge a subject of discussion. The same applies, for instance, to Bullinger et al. (2004: 3351) who underlined the role of face-to-face contacts in knowledge constellations where tacitness is a critical factor. Powell et al. (1996) analyse network relations which are marked by multilateral learning process. Owen-Smith and Powell (2004: 17) demonstrate inter alia the importance of institutional characteristics of key actors and proprietary arrangements for the knowledge exchange processes.

In spite of the multitude of respective studies, there is a lack of systematic analyses of the whole range of relevant features which influence knowledge exchange processes. Our contribution intends to show that there are open research questions which cannot be answered satisfactorily at the moment. Thus, a stronger attention to the mentioned structural characteristics would be useful for innovation network research because:

- a systematic examination of factors that influence the genesis, evolution, innovative contributions of innovation networks and are able to explain obvious differences between such networks might contribute to the further development of the emerging innovation network theory;
- the consideration of any of the structural characteristics discussed can do its bit to improve the explanatory power of formalized models on innovation networks;
- these structural features may help to explain seemingly paradoxical results of model-based empirical works on innovation networks that contradict the researchers' theoretically inspired expectations;
- their consideration could help to close the gap between management-oriented network studies and formalized social network analyses, respectively, between qualitative and quantitative research.

In our paper, we demonstrate the role of these structural characteristics for innovation networks at the example of material on the German 'Leading-Edge Clusters Competition' (LECC, Spitzencluster-Wettbewerb). Thereby the illustrative purpose with regard to the discussed structural peculiarities is central, whereas rationale and effects of the LECC programme or similar cluster programmes aresubject of the discussion in Rothgang et al. 2017. The LECC is well suited as demonstration object for such a discussion because it aims at enhancing innovation networks among firms and research organizations in different sectoral constellations. Although such structural traits are present in every innovation network, innovation networks distinguish themselves strongly by their manifestations. The contribution argues that formalised analyses of social networks could be further developed by taking into account actor heterogeneity, contexts of networking activities; and diversity of knowledge exchange processes.

Our paper is explorative in its nature and based on qualitative research done in the framework of the LECC evaluation. It introduces core structural characteristics of research networks as research topics and thus raises new research issues. In section 2 the LECC programme and nature of the used research material are presented. In section 3, the theoretical context in the framework of network research is discussed, followed by the presentation of qualitative empirical findings in section 4. Section 5 draws conclusions.

2 The LECC as Demonstration Object

2.1 The LECC Programme and Networks

The projects funded in Germany's LECC by the Federal Ministry of Education and Research (BMBF) were initiated in 2008 and continuing until 2017 (BMBF 2015). This program differs from other cluster programmes in several respects. These are the volume of R&D financing (other programmes mostly being endowed with considerably smaller financial means), its national and international visibility, and its openness with regard to the whole spectrum of high-tech industries/technology fields. Another distinctive feature

is its unique combination of bottom-up and top-down elements in the selection of Leading-Edge Clusters (LECs) among the field of applicant cluster initiatives (Rothgang et al. 2014: 15-18, 47-57).

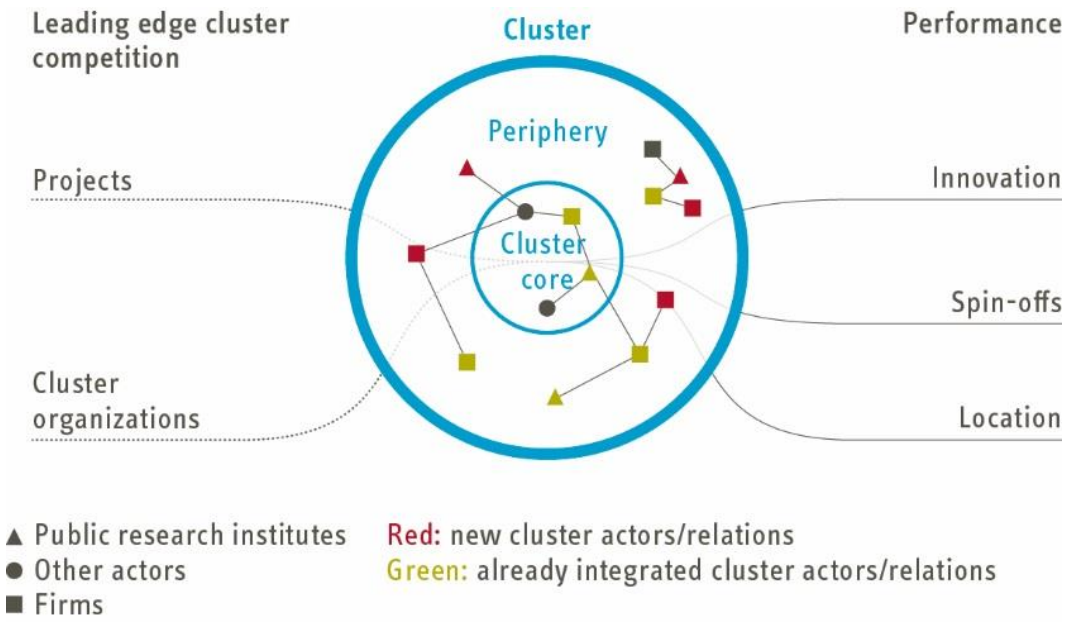
The fifteen LECs that were successful in the competition were operating in twelve science-based technology fields, three belonging to red biotechnology (personalized medicine). Each LEC received an amount of up to € 40 million which was paid out over a 5 years period. Up to 85% of the public financial means disbursed under the programme were spent for collaborative research projects of cluster firms and research organizations. Thus, mostly joint research projects of large firms, small and medium sized firms, higher education and research institutions (below denominated as 'research organizations' - ROs) received funding under the LECC. A smaller part of the financed projects was dedicated to educational and organizational tasks. Public funds had to be co-financed at least at 50% by the receivers of the subsidies.

What does 'networking' mean in the context of the LECC? – Potential candidates among the applicants were encouraged to set ambitious development targets for their clusters that had to be laid down in written 'cluster strategies' in the course of the application process. The LECC promoted the successful cluster initiatives in implementing their strategies with the aim to reach the visionary targets for the cluster's long-term development. The implementation of the cluster strategy was to be steered and monitored in each LEC by a joint organization of the cluster actors (cluster organization) that performed the duties associated with cluster management. The performance of the clusters was measured by indicators, such as innovations, spin-offs, start-ups, and establishment of subsidiaries in the cluster area (cf. figure 1).

The public promotion of joint R&D projects, which bring forth or enhance the cooperation between different types of organizations (firms, ROs) is also common practice in other network programmes. Additional specific features of the LECC, at least partly shared with other complex cluster and network programmes, are the strong role of a viable supporting structure, the cluster organization, and the active supporting role of the programme administration, the latter being represented by the project management organizations (Projektträger) of the BMBF.

According to the concept of the programme designers, the cluster organization should not only function as mere organizational unit for the implementation of the cluster projects. It functioned as enabling structure responsible to strengthen and develop the innovation network of the cluster as well inwardly as outwardly. Hence, the cluster organization was to function as a sub-network of the wider cluster innovation network, which enhances and generates separated sub-networks organized around the common cluster strategy.

Figure 1: Networking between Actors in LECs



Source: Own depiction.

Social network analysis of the innovation networks in the 15 LECs was part of the evaluation study carried out on behalf of the BMBF. Here, a major finding was that a considerable expansion of the existing research networks took place due to the cluster promotion (Cantner, Graf, Töpfer 2015; Rothgang et al. 2014: 117-133). In many cases, research contacts between participating firms and research organizations were newly established, whereby the initiative mostly originated from firms. Smaller firms found a chance to cooperate for the first time with larger enterprises in joint research projects. The LECC has led to a greater density and a higher degree of centrality of the existing networks and strengthened the central role of single actors, mostly large firms, but in some cases ROs.

2.2 Empirical Basis of this Contribution

Our analysis is based on data which were collected during an ongoing evaluation of the LECC on behalf of the BMBF. The evaluation project extended over a period of more than five years between 2008 and 2014 (Rothgang et al. 2014). Two main sources were used: Firstly, two written surveys of project managers in all research projects of the 1st and 2nd competition round which were conducted about four years after the commencement of project funding (in 2012 for the 1st round and in 2013 for the 2nd round). Secondly, expert interviews were conducted in 2013 with cluster actors (firms and research organizations) and cluster managements in which questions on networks were posed.

The interviews provide insights about the programme implementation in the respective cluster, properties of its innovation network(s), evolution of the organisational structure of the cluster initiative, and the realization of the set targets. Thus, they deliver on the one side information on the singularities of each cluster initiative, sectoral specifics as well as individual observations. On the other side, they are used in our analysis in order to infer from the comparative study of several individual cases general insights in knowledge exchange contexts, infrastructures, and processes that are relevant for all LECs and other innovation networks (for the relevant discussion on methods, see Becker 2017; Cramer 2016; Kelle 2007). This makes qualitative interviews a valuable source of empirical information in addition to written/electronic documents and descriptive statistics on the clusters.

The results of 56 semistructured interviews of about one to three hours were analysed (25 in the clusters of the 1st and 31 in the clusters of the 2nd round). One of four parts of a fixed interview guide included questions on network development (effect of the programme on the individual networks) and knowledge exchange due to the programme. We interviewed representatives from small and medium sized companies, large companies, universities, and research institutes, which were members of the cluster initiatives. For our characterization of network development, we analyse the answers to our questions. In order to identify the source of the information and at the same time to provide anonymity of the statements, the quotes are related to the individual interviews. The first number denotes the number of the interview, the second the number assigned to the cluster.

3 Theoretical Background

While the general benefits of engaging in social networks (Smith-Doerr, Powell 2005: 379) are also relevant for innovation networks, their specificity in comparison with other types of social networks is based on their contribution to the processes of knowledge creation and diffusion. The exchange of knowledge between interacting partners with regard to the solution of technical and scientific problems is their rationale and ultimate purpose. Historical evidence shows that the process of technology evolution was of a strongly collective nature already in early phases of industrialization despite the outstanding role of single inventors and entrepreneurs (Mokyr 1990: 273-299).

Among the forces driving the emergence and evolution of innovation networks is, as Cantner and Graf (2011: 367-387) show, triadic closure, the tendency of actors to forge ties with their partners' collaboration partners. Network structures are initially marked by weak ties and many structural holes. These are gradually replaced by structures that are characterised by strong ties and a reduction in the number of holes. Another driving force are, according to Cantner and Graf, preferential attachment and path dependency. Actors, who dispose already at many ties with others, attract additional alliances and thus strengthen their central position in the evolving network. This leads to the typical centre-

periphery structure of many innovation networks which are marked by a highly skewed distribution of the number of ties per actor.

Given these observed patterns of innovation network development, our focus is on three aspects of innovation networks: actors, kinds and contexts of networks and contents as well as channels of knowledge transfer. In each case, we focus on a few theoretical assumptions, which only form a small section of the larger body of relevant knowledge.

The ***actors*** who engage in innovation networks can be either individuals or (more or less complex) organizations. All participating organizations, even the smaller SMEs and ROs, represent for their own part innovation networks consisting of organizational sub-units and individuals. As has been emphasized by actors-network-theory, the technical devices human beings have created to support research activities such as laboratories or large-scale technical systems are also constituent parts of innovation networks (Bellinger, Krieger 2006). In the LECC, joint laboratories are important in some cluster organizations.

As soon as organizations are formally involved in networking, innovation networks connect individuals and organizations in varying combinations. Organizations cannot act in networks as collective entities, but have to rely on the involvement of the individuals acting on their behalf. The same applies to the participating sub-units of the complex research organization of a large enterprise, which may assemble a broad spectrum of relatively independent research units.

We take up the actor perspective in *section 4.1* and ask (1) *what kinds of actors* are involved in the LECs, and (2) *how the special features of the diverse actors influence their role in the network interactions*.

Inter-organisational ***innovation networks*** are characterised by a high diversity of network relations (cf. the analyses in Stegbauer, Häußling 2010). A critical analytical question consists in the analytical delimitation of the networks that shall be analysed. Innovation network structures such as those we observe in the LECs are marked by a high degree of complexity. Smaller networks are embedded in larger ones connecting a wide array of individual actors and organizational (sub-) units. The innovative potential and evolutionary prospects of single smaller innovation networks cannot be adequately assessed by their isolated analysis. Rather, the wider network, respectively in the case of a cluster its whole ‘innovation system’, has to be taken into consideration. The operation of networks in innovation-oriented inter-firm contexts can only be fully understood if their contexts such as their sectoral, economic and societal environments are taken into account (see, for instance, the studies in Padgett, Powell 2012).

The structural holes loosely linking different more or less thick parts of wider networks, firstly scrutinized by Burt (1992), should have an extraordinary importance for innovation networks especially in emerging and ascending fields of technology. Burt’s analysis emphasized the advantages, which network actors can derive from brokerage opportunities

based on the maintenance of relations with network partners whose networks are not connected among each other. From an innovation perspective, detecting and closing structural holes might create new opportunities for technological evolution. The network of researchers who are active in different parts of a technology field or adjacent fields might inspire the recombination of existing technological solutions and the search for new ones. The popular network promotion approach, which tries to bring together firms and academic researchers, aims at bridging a widespread type of structural holes.

In their analysis of network relations, Amin/Cohendet (2009: 42-47) distinguish three domains of firm activities with differing consequences for the type of networking practised in each of them. The core area entailing the heart of firm competences is strictly shielded from competitors and undesired observers. Innovation network relations in this domain are exclusively to supplier firms and are subject to strict contracts and organizational rules. The second domain (competence domain) is characterized by more open relations with external partners who are not bound by contracts. Partially, even joint precompetitive R&D results that are developed together with competitors belong to this domain. The third – 'peripheral'– domain is characterized by normal market relations, which are complemented by network relations.

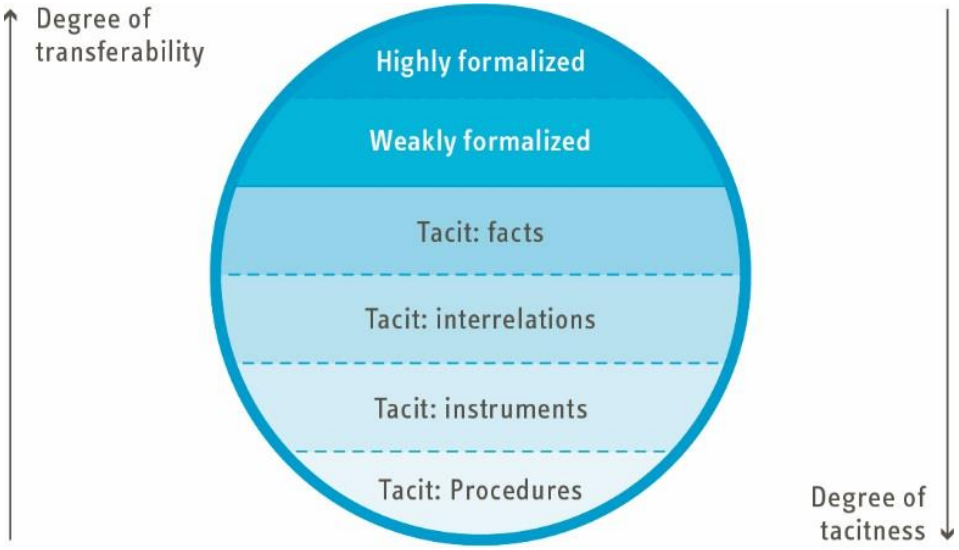
In *section 4.2*, we take up the network perspective and consider, *what kinds of networks exist in the LECs and what functions they perform in the context of the larger innovation network of the cluster*. We further analyse *the special role of the cluster organization* and *how the LECs address structural holes*. Based on the described domain typology of Amin/Cohendet, we discuss the *diversity of promoted network relations in the LECs*.

A closer look at the ***contents and channels of knowledge exchange*** shows that the "pieces of" knowledge transmitted are anything else but a homogenous entity. Knowledge is a highly differentiated 'matter', which is difficult to grasp. Knowledge may have an explicit character, which means that it can be formulated in a natural or formal language and is easily transferable. Otherwise, it is of a tacit, implicit, hidden nature and thus cannot be or is not expressed in terms of a verbalized language (Polanyi 2009: 3-25). Bearer of both forms of knowledge can be either individuals or organizations. Explicit knowledge occurs in the case of individuals as embrained knowledge (tied to the individual mind) and in the case of collective bodies as encoded knowledge. Implicit knowledge is designated as embodied, not consciously reflected on knowledge with individuals and as embedded knowledge with organizations (cf. for this classification Frost 2010).

Cooperation in networks opens the principal chance to get access to knowledge which is available in a more or less codified form. Thereby, the degree of transferability of the information shows a negative correlation with the degree of 'tacitness' (Nelson, Winter 1996: 80-82). As is shown in figure 2, highly codified information, such as written descriptions of technological concepts and procedures can be easily transmitted and do not require personal translation of the individuals who participated in the knowledge exchange. However, tacit knowledge about the use of instruments and concrete procedures

is difficult to transmit, even if the 'owner' of this tacit knowledge should be willing to transmit it to the receiver.

Figure 2: Types of information transferable in knowledge exchange



Source: Own depiction.

As Knorr-Cetina demonstrated (2012: 235-7) by using the results from her laboratory study, the implicit knowledge which is relevant for a 'community of practice' of scientists is by no way shared by all its members, but is often highly idiosyncratic, and thus restricted to a small circle of individuals or even to a single person. Cowan/David/Foray (2000) pointed out that, given the heterogeneity of tacit knowledge, only a part of it would be principally suited for the translation into explicit forms.

In *section 4.3*, we take up the discussion on the exchange of implicit and explicit knowledge in order to address the question, which *patterns of knowledge exchange could be observed in the LECs*.

4 Empirical Findings from the LECC Evaluation

4.1 Actors in LEC Networks

The cluster initiatives representing the LECs are organized around ambitious technological and economic targets, which had been formulated in a strategy paper. The group of 15 LECs was very heterogeneous with respect to sectors/technology fields and to their local and regional environments. Thus, it should not be surprising that the number of participating cluster actors strongly differs, the number reaching from just 18 (Forum Organic Electronics) to 251 (MicroTEC SüdWest), the average being 112.

The number of formal cluster partners (actors actively participating at the cluster initiative) depends on the one hand on the cluster actor population – number of firms and ROs

belonging to the addressed field of technology which are active in the cluster region. On the other hand, the number of partners is associated with the degree by which the cluster initiative could motivate relevant firms/ROs in the cluster area to participate in the joint activities. For the five LECs of the first LECC contest round, our evaluation study could identify 600 relevant actors in the cluster areas which were no members of the cluster initiatives among a total of 1.000. A large part of the 600 non-participating actors was connected indirectly with the cluster initiative by, for instance, supplier links. 400 actors participated, 200 of them benefitted from public project funding (Rothgang et al. 2014: 51). This shows, that different organizations are attached to the programme activities in different manners and intensity and that an analysis of the LECC induced innovation networks ought to take into consideration not only the formal member organizations, but also those organizations that are linked in indirect ways to the cluster initiative, provided that the collection of respective data is feasible.

In the LECC context, cluster actors are organizations consisting for their part of individuals. Among the participating organizations, different groups can be identified:

(1) *Large enterprise* (LEs) with rather different firm sizes, sectoral affiliations, and research capacities are active in the cluster organizations. In most instances (Airbus forming an exception), only a small division of the firms is present in the cluster area with internal research capacities. The financial means spent by these firms for the technology field of the cluster project absorb in most cases only a rather small part (1 to 5 %) of their total R&D expenditure.

(2) While the LECC was not conceptualized as a promotion programme for technology-oriented *Small and Medium Sized Enterprises* (SMEs), the latter play an important role in all 15 LECs and are thus an indispensable component of the cluster promotion. In BioRN, it's OWL and Solar Valley, a large share of core cluster actors are SMEs, in others like Hamburg Aviation, SME representatives are also involved in important positions.

(3) The spectrum of participating *Research Organizations* (ROs) is extremely wide. Some are active in the cluster organizations through their central administration like Ruprecht-Karls-Universität Heidelberg (FOE), others through separate university departments or institutes. Other important ROs are and independent research institutes working in the respective technology field such as Fraunhofer Institute for Material Flow and Logistics (IML) Dortmund (EffizienzCluster Logistics Ruhr). In the case of the larger institutions like universities, only a small fraction is actively engaged in the cluster activities.

(4) *Cluster organizations* are organizational units that consist on one side of a cluster management organisation that hosts several employees for different tasks (like representing the cluster organization, marketing of activities initiated by cluster initiatives or developing member relations). On the other side, there are cluster boards where representatives from the cluster actors meet to discuss common activities that exert influence on the evolution of the cluster initiative, respectively the cluster (Rothgang et al. 2014: 128).

(5) The group of *other organizational bodies* that relates to the cluster organizations was rather diverse, including representatives from the local economy and society, educational organizations, as well as other network or cluster organizations. In some cases, such institutions are formal members, in other cases they have formally committed themselves to support the cluster initiative. In exceptional cases they may have an impact on the evolution of the innovation networks in the cluster, for instance, by encouraging newcomer firms to cooperate.

While the development of networks between organizations display one important aspect of the programme effect, structural characteristics in respect to the behaviour of individuals who are part of the networks are additionally important to understand knowledge exchange on a smaller scale and, finally, the effects in respect to innovation or other economic dimensions. Among these individuals are brokers, mediators and motivators who enhance the expansion of the innovation networks within the cluster and with outside actors. The by far largest group of individuals involved in the LEC activities are the researchers and developers from ROs, LEs and SMEs.

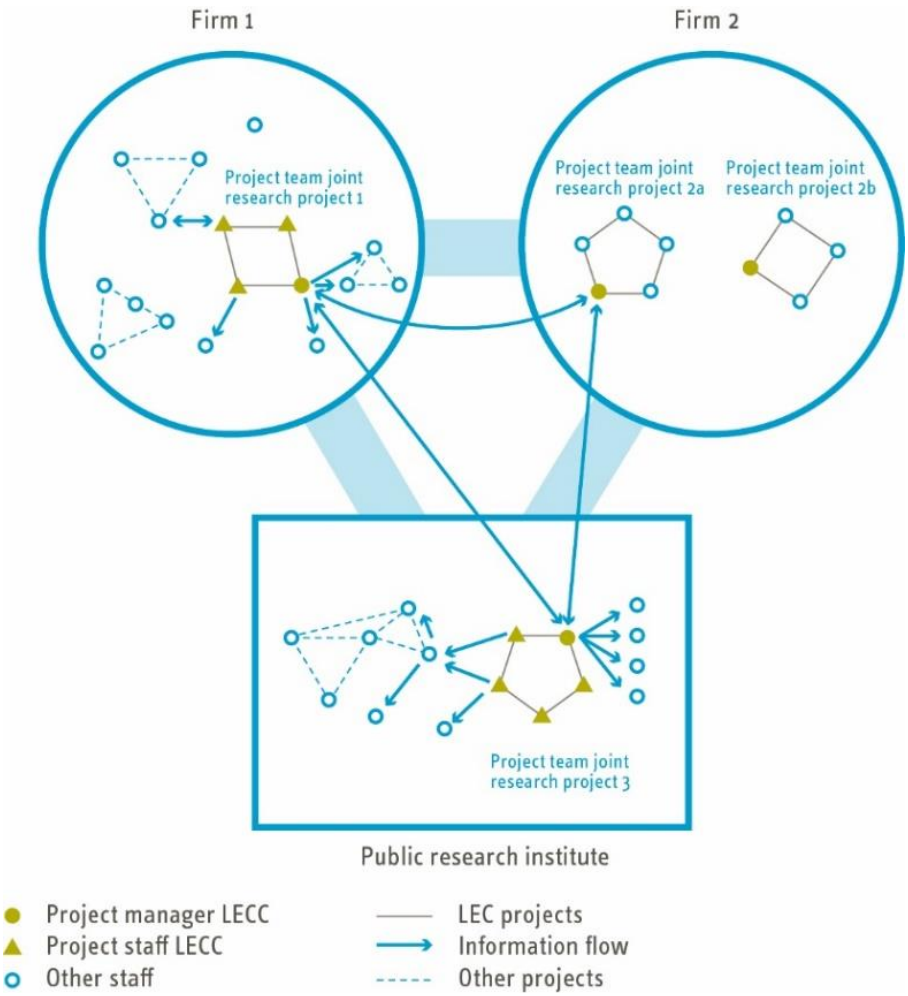
The complexity of the ensuing innovation system of the cluster on the level of individuals is illustrated by figure 3. The figure shows only a very small segment of the larger innovation network, which comprises only two firms and one public RO. Project leaders of the sponsored R&D project form the official links between the project sub-groups situated in three organizations. In firm 1 and the RO the LEC project is connected with other projects which are not financed out of the LEC funds. At the same time, there is a broad variety of research contacts of the 11 researchers which are engaged in the LEC project among themselves and with other research staff inside and outside of their organization.

As we observed during our research, the knowledge exchange processes inside the cluster firms and ROs are highly diverse and manifold: Start-ups and small enterprises are mostly characterized by a concentration of core information and knowledge in the hand of a few individuals (e.g. the manager(s) of the firm). There were several examples in our interviews where this was the case (e.g. interviews 2/6, 2/4 or 4/7). In that case, diffusion of knowledge takes place through the manager as information broker who often has most of the knowledge relevant for innovation activities.

In large firms, competences are divided between different departments. In some cases (multinational enterprises), departments even compete also with the knowledge they develop in cooperative research projects (interviews 1/4 and 3/10). At the same time, the diffusion of external knowledge is dependent on the routines developed within the firm and the individual actions of the responsible knowledge broker (either a manager who is active in a cluster board or a project manager who gains knowledge in his/her project activities, see e.g. interview 1/4). There were also several cases, when strategical firm decisions influenced the networking activities significantly, either with the project oriented network being cancelled or stopped (interview 3/1, interviews 1/4 and 2/4):

> *In one LE, a project was internally stopped in the middle, because the research target did not fit into the firm strategy any more. The cooperation came to a halt. At a later point in time, the firm strategy was adjusted again and the project work and therefore the network activity was taken up again.*

Figure 3: An LEC R&D project linking two firms and a research institute



Source: Own depiction.

In universities, departments or chairs often act as isolated units in such a way that information often is not spread by routines between different sub-units (e.g. interview 2/6). Knowledge exchange then happens more by chance or through personal relations than in any systematic manner. Thus, from a knowledge exchange point of view, it would often be more appropriate to view chairs as network nodes than universities.

To sum up, the treated structural characteristics of innovation networking show a large diversity of actors, who are often by themselves highly complex organizations with internal and external sub-networks. Taking these aspects into account increases the explanatory power of network analyses for several reasons: Firstly, decisions, the organization-internal division of information and internal processes (e.g. in decision making) are important for understanding network effects. Secondly, our observations indicate that individuals represent organizations on a formal level, but their actions (e.g. whether to diffuse

project internal knowledge within the organization) are important for the effectiveness of the total network.

4.2 The Observed Diversity of LEC Innovation Network Relations

The larger innovation networks of the 15 clusters represented by the LEC cluster initiatives comprise essentially five components, which could be designated as sub-networks forming the 'cluster innovation system' and are delimited depending on criteria like use of LEC funds, participation in LEC activities, degree of formality of relations, and participation in steering activities of the LECs. When looking deeper into these relationships, we can identify different layers and groups of sub-networks even at the level of organizations:

(1) The network of R&D related formal cooperation relations between the cluster actors (LEs, SMEs, ROs) which benefitted from public financial means LECC R&D project funding. Formality is related to R&D cooperation contracts either in the LECC context or in other public funding or private cooperation projects. This part of the greater cluster network was the primary object of the empirical study of innovation networks in the evaluation study (Rothgang et al. 2014: 117-133; Cantner, Graf, Töpfer 2015).

(2) The network of R&D related formal cooperation relations between cluster actors (LEs, SMEs, ROs) who did not receive public funds, but were listed members of the cluster initiative. As in case (1), these network relations included cooperations with outside partners.

(3) The network of R&D related formal cluster-internal and cluster-external cooperation relations of firms/ROs that did not participate in the cluster initiative although they were active on the addressed technology field and located in the cluster area.

(4) The more or less tight informal innovation-oriented contacts between all cluster actors independently of cluster initiative membership and public funding which did not cross the threshold to formality.

(5) The relations between representatives of the cluster organization and cluster actors aiming at strengthening and expanding existing innovation networks within the cluster area as well as with third parties outside the cluster area.

The borders between (1), (2) and (3) are fluent and the respective sub-networks are closely linked among each other. Sub-networks (4) and (5) are components of the cluster innovation system, which owe their existence – like sub-network (1) – at least partially to the LECC programme. Network 5 is characterized by a small number of core persons that are actively involved in the development of the cluster strategy and the majority of members of the cluster organization that are only involved in some parts of the decision-making processes. In most cases, members of network 5 also belong to network 1. Network (1) also involves the firm/RO employees who participate in the research projects who are mostly not identical to the participants in network 5. The role of network (4) is due to its informality hardly to delineate in empirical investigations but should not be underestimated. The following discussion is focused on the innovation network of sponsored actors (1).

Due to the LECC, firms and ROs in the cluster area, which didn't maintain previously formal, in many cases even informal contacts, found the opportunity to establish contacts

among each other for the first time. Even in many cases, in which the financing of collaborative R&D projects out of the LECC funds were not feasible, formal or informal contacts between new partners were established. In our analysis, we found some instances where we could identify structural holes that were closed in the LEC induced networks: Examples are: (1) Many SMEs (especially young firms) which had previously no contacts either to the relevant ROs or to the LEs located in the cluster area, got the chance to establish contacts deepen relationships, and, as funding recipients, to participate in joint research projects. (2) In some cases, the cluster activities brought together firms from rather different domains and sectors that combined their knowledge to produce new products or services (see e.g. interview 10/5).

Regarding type 1 innovation networks, our evaluation study showed that the implementation of the programme succeeded in initiating new R&D cooperations and strengthening existing partnerships (Cantner, Graf, Hinzmann 2014; Cantner, Graf, Töpfer 2015; Rothgang et al. 2014). As conceptual framework for the discussion of selected structural characteristics in these expanded innovation networks, we make use of the domain concept developed by Amin and Cohendet (2009).

Our analysis showed specific sectoral patterns with respect to the extent but also to the contexts in which new core cooperations of the 1st domain developed which is to be demonstrated by three sectoral examples:

- In the Software Cluster, the existing cluster networks, which are arranged around a core actor (SAP) have been intensified due to competitive pressure (interview 3). The cluster networks are characterized by sector characteristics (very few large firms, a large number of small firms). The cluster initiative has made it easier for small firms to cooperate with the large firms. At the same time, there were reservations of some cluster firms about their dependence on the core firm in their cooperations (e.g. interview 5).
- In contrast, the difficult market situation of the cluster actors in the cluster Solar Valley partly impeded an expansion of the cluster networks at least on the firm level (interview 5). The reason was the competitive pressure from Chinese producers of solar panels and related products. At the same time, cluster activities have led to increased research cooperations of some beforehand hardly research-intensive actors in their core competitive fields (interview 7).
- The Effizienzcluster LogistikRuhr is positioned in the logistics sector in which nearly no firms perform own R&D such that the set up collaborative research projects are borne primarily by two ROs. Firms are then involved as practice partners who provide the surroundings for testing and implementing the research results. Multiple research cooperations were newly initiated even if a smaller part of the actors had already cooperated with their project partners before (interview 6). In most cases, firms provide necessary practical information and environments and the research is performed by the research organizations.

Cooperations in the 2nd and 3rd domain encompass (i) research cooperations in the framework of research projects not directly connected with the firms' core activities, (ii) information exchange and transfer in the context of the cluster organizations and the existing boards in connection with the elaboration and further development of the cluster strategy. The cluster organizations often function as platform for new contacts and cooperations,

being important for networks in the 2nd domain as well as for information exchange in the cluster's field of technology, thus addressing the 3rd domain (e.g. interviews 3/5 and 6/5). The knowledge is transferred by individuals participating in the exchange of information (as representatives in cluster boards, project managers and collaborators). From the more or less informal meetings or discussions in the cluster boards, new ideas for joint research projects arose (e.g. interview 3/1).

From the different patterns of the cluster actors' involvement in cluster related networks, it also becomes clear that the degree of integration into the cluster network differs quite substantially between the actors with clear cluster specific patterns. While some firms are closely integrated in all (also the strategical) cluster activities and also exert active influence on the strategy's further development (interview1/4), others are only involved in the funded projects and receive email information on cluster activities (interview 3/4). Thus, independently of the number of network relations, the cluster networks have a differing relevance for firm activities. In some cases, the relevance proved to be comparable with other promotion programs, in other cases, clear specifics became obvious (interview 3/4).

To conclude, the larger innovation networks (innovation systems) of the LEC are characterised by the interplay of different sub-networks among which the steering network of the cluster organization plays a central role. These different networks and their shape are important for understanding programme effects as they have different targets and degrees of intensity. Expanding and newly created innovation networks filled in many cases structural holes in the previously existing networks and thus opened new chances for cooperative innovation activities. The concept of domains proves to be suited to display the diversity of innovation network relations in the LECs. The program impulse of the LECC for cooperation networks influences existing and emerging networks in all three domains.

4.3 Paths and Contents of Knowledge Exchange in the LEC Networks

While knowledge exchange may relate to different types of knowledge and thus can have different functions or relevance in organizational contexts, the precise circumstances of the exchange of knowledge (i.e. the nature and target(s) of the knowledge exchange) between individuals and organizations are also highly diverse. This aspect can be illustrated by looking at examples of knowledge exchange in the LECC.

Network constellations lie in the triangle between exchange of formalized knowledge, exchange of tacit knowledge, and the combination of the different knowledge stocks of the participating ROs to produce a common R&D output. Exemplary constellations that lie in the angles of this triangle are:

– In many LECC project contexts, the knowledge is not so much transferred from one organization to the other but rather the output of different knowledge pools is *combined in order to produce a specific project result*. In this case, the knowledge of different organizations is then 'transferred' into a specific outcome of the research project (e.g. when software competence of a firm is combined with hardware expertise of another firm to produce a product with software control). Here, knowledge could possibly also flow directly between the participating

actors as a kind of side-effect, but the combination of knowledge is the main target of the activity.

- In other cases, *implicit knowledge of different domains* is transferred in the research process. This is the case when new materials (like carbon composites) are used in construction of new products like car bodies. In such cases, the knowledge of materials experts has to interplay closely with the knowledge and skills held by the car body design experts. In order to enhance this kind of exchange, research activities in certain industries and also in new fields where different competences have to be combined in R&D, are increasingly performed under one roof. However, also under these constellations, only certain parts of the R&D process are performed together, while others are shielded from the partners. Such facilities for common research activities have been developed in clusters 3 and 4 (in the case of cluster 3 the laboratory has been established as a result of the LECC, cluster 4, the LECC has contributed to its development, see interview 4/5).
- A third constellation can be observed when networking has the primary goal of keeping up with new trends and activities that take place on a national and international level, being associated with the *transfer of formalized and accessible tacit knowledge*. In this case, the firm develops networks in order to provide a one-way information inflow to increase the knowledge about new market developments and technological trends. To attain such knowledge has been one important motive for firm participation in the LECC (Rothgang et al. 2014: 187):

The collaborative research activities we observed in the LECs are usually a combination of these (and partly also other) constellations. As information is obtained from the common activities (either from the project partners or from other actors), this information is transferred to and exchanged with other projects of the firm.

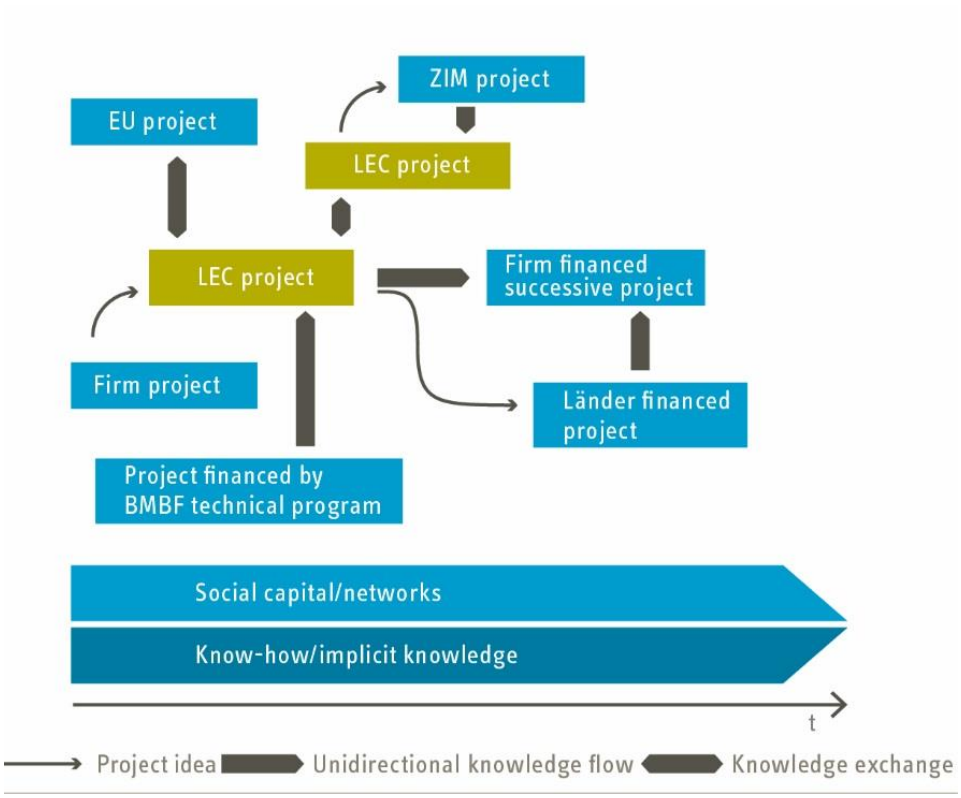
This is also the case for the research projects financed under LECC, which are in many cases components of a 'micro cluster' of related projects in the same field of technology. These other projects are either financed by the firms themselves or by public authorities (see figure 4). Similar patterns can also be found in ROs (interview 10/5).

These projects may be carried out either by individual firms separately or jointly with external project partners, the structure of research partners mostly differing from the partner structure of the LEC projects (e.g. interviews 1/1, 4/4, 4/6). The technological relations between these projects could take on differing shapes. In some cases there is a narrow relationship as regards research questions and methods between LEC and non-LEC projects, in others one project precedes or continues the other. In some cases, the close link might require a permanent exchange of results, in others a loose, sporadic information between the project leaders may be fully adequate with regard to the firm's overarching interests.

Based on two surveys of project managers in the LECs, table 1 shows the observed patterns of project knowledge exchange beyond the individual LEC project. The project results are often diffused within the organization beyond the project team or used into other project contexts. However, knowledge exchange within the project network between dif-

ferent organizations takes place not so often (in 30% of the cases, in further 36% partially). Knowledge exchange outside the project network is not the rule, however, there are also project contexts out of which knowledge is transferred outside the networks.

Figure 4: LEC projects as part of complex project activities



Source: Own depiction.

The analysis in this section shows, that innovation network activities trigger and influence widely varying structural patterns of the knowledge exchange and use. This picture explains why it is so difficult to relate network development to performance indicators and at the same time points to aspects that could be integrated into future network analyses: The relevance and economic effect of these patterns depend on context-specific factors. The channels of knowledge exchange are manifold and connected with all sub-networks of the larger innovation network of the cluster that should be integrated into the analysis. Project cooperation forms one essential basis for knowledge exchange. Tacitness of a part of the relevant knowledge was present in all observed research contacts, but hardly to measure empirically. In many common projects, the joint solution of a technological problem is the exclusive task of a project, which is, apart from this, not connected with any further exchange of knowledge. In other cases, research cooperation may offer opportunities for an extended exchange of explicit and – at least to a certain degree – also

of implicit knowledge. Thus, it seems also important to ascertain, when and in what contexts knowledge actually flows between different actors (either individuals or organizations).

Table 1: Patterns of project knowledge exchange beyond the individual project

	Applies totally	Applies partially
Members of the firm/research organization outside the project team were informed about project results	52,7	32,9
Project results could be used in other contexts	30,6	38,3
Intensive information exchange with other projects in the project network	36,7	36,0
Intensive information exchange outside the project network	14,2	29,9

Source: Survey of project managers, 1st competition round of the LECC (2012) and 2nd competition round of the LECC (2013). N=480 (only projects with multiple partners). Item 2 was only asked in the 1st round (n=222). Five possibilities from "applies totally" to "does not apply", displayed are the shares of answers in the first two categories.

5 Discussion

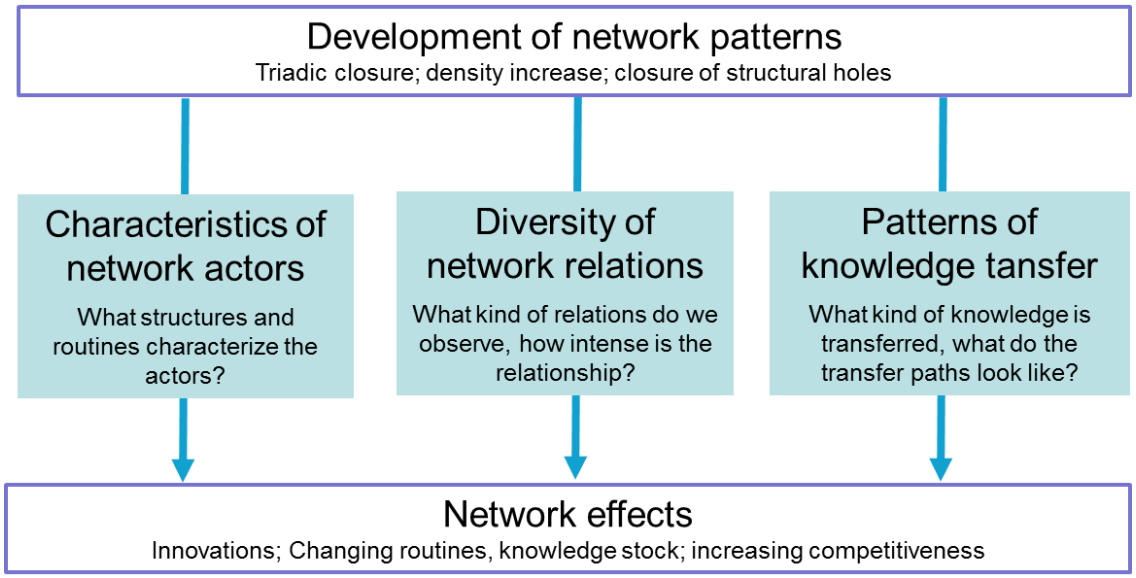
Our contribution draws the reader's attention to selected structural characteristics of innovation networks that seem to be relevant to better understand how networks function and – eventually – what effects they have on economic variables (figure 5). These become obvious in qualitative network studies and accessible in formalized social network studies. The paper traces some of these facets of networks by looking at the LECC as demonstration object. It is at the same time important to note that there are other, additional aspects that have not been discussed here (like, for instance, the influences of power, formal and informal hierarchies, social norms, trust, motives, learning processes – cf. Brass et al. 2004).

The paper addresses the characteristics and heterogeneity of actors, the diversity of the ensuing innovation network structures and the patterns (i.e. channels and contents) of knowledge exchange. Our analysis is explorative in nature. The paper primarily aims at asking questions, which are important for the further refinement of network research, but does not assume to offer ready answers.

The ***actors*** who constitute the innovation networks in the LECs by their interrelationships are rather diverse in respect to their characteristics. Large and complex globalized firm organizations having thousands of employees encounter SMEs employing less than 10 employees. Independent ROs of an utterly modest scope participate in the joint R&D projects together with universities having themselves a highly complex structure. As our experiences show, it is important to consider not only the participating organizations, but

also the role of individuals and their behaviour and the inner-organizational structures and processes when analysing the effects of network development. A clear potential to improve future analyses of network research consists in taking into consideration the position and embeddedness of the cooperating sub-units in their larger organizational contexts.

Figure 5: Core factors that influence network effects



Source: Own depiction.

The contexts and the delimitation of the ***innovation network*** to be analysed is critical for the explanatory power of ensuing analysis. In the case of the LECC, we found different kinds of networks in all LECs consisting of a multitude of partially directly connected, partially relatively independent from each other. We saw that the LECC influenced these different kinds of networks with a different degree of vicinity to the core business of the individual actors. The effects of network development and the relevance of structural holes are, as we experienced, very much dependent on the context (e.g. sectoral characteristics) which should be taken into account in future work. Our experiences show that understanding the domain of network activities (i.e. how close the network projects come to the core business of the participating organizations) is one important dimension. In order to understand the effects of cluster programmes and similar programmes, it is important to consider the role of the steering network and its ability to contribute to the expansion of the inward and outward innovation network.

With regard to the ***patterns (contents and channels) of knowledge exchange***, our analysis shows, that the use and exchange of knowledge is rather context specific. In many cases, combination of knowledge is the main purpose of a cooperation. At the same time, there is no completely free and unrestricted knowledge exchange in innovation networks

relations. All knowledge exchange transactions are limited by the organizational embeddedness of participating individuals, by the impossibility to simply transfer tacit knowledge and by a host of psychological factors facilitating or impeding the transfer of knowledge, which is relevant for the involved organizations and individuals. For further analyses, this poses the challenges to identify and model patterns of knowledge flows in order to contribute to a better understanding of the effects of innovation networks.

Our analysis points to open questions for future research work that are closely related to the topics just addressed. In answering these questions, the aspects discussed here should be of key importance. The question, how inter-organizational innovation networks influence or improve the innovative and general economic performance of firms is presently still open. Innovation policy measures destined to enhance innovation networks should take into consideration the given circumstances such as sectoral experiences of networks, the participating actors' capabilities or the organizational contexts of the networks to be promoted.

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