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by

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# Policy induced innovation networks: the case of the German "Leading-Edge Cluster competition"

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## Abstract

The last decades saw a pronounced shift in innovation policy in Germany and many other countries towards increased funding of cooperative R&D. Over the last years, competitions between regional initiatives pushed this trend even further by adding a regional perspective, by increasing the scope of funding, and by fostering interaction between a large number of actors. In 2008 the German ministry for education and research (BMBF) started the "Leading-Edge Cluster competition" ("Spitzencluster-Wettbewerb") in which 15 clusters were selected in three waves (2008, 2010, 2012) and are funded for a five-year period with up to 40 million Euro each. Our paper presents selected results regarding the influence of government funding on cooperation networks within five of the clusters that were successful in the first wave of the "Spitzencluster-Wettbewerb". More specifically, we analyse the extent of policy influence on the network of most important cooperation partners, its geographic reach, and the changes of network structure in general. Our empirical analysis is based on original data that was collected in 2011 with cluster actors (firms and public research) who received government funding. Our results indicate that the program was quite effective in initiating new cooperations between cluster actors and in intensifying existing linkages. The vast majority of the linkages which are influenced by the cluster competition are between actors located in the cluster region. With respect to the influence of the cluster competition on network structure, we find an increase in network centralization. Small and medium sized enterprises used the chance to connect with the local 'stars', but not as much among each other.

**Key Words:** Cluster, Innovation Policy, Evaluation, Social Network Analysis

**JEL:** O3, O38, L14, R1

## 1. Introduction

The introduction of the BioRegio contest in the early 1990s marked the beginning of a new era of R&D funding programs. The German innovation policy experienced a paradigmatic shift away from traditional R&D funding measures towards contests between regions with a special focus on collaborative R&D projects. Central to these new competitive approaches were the stimulation of interregional competition, promoting the establishment of regional clusters and the improvement of the functionality of the regional innovation system (Staehler et al. 2007, Eickelpasch & Fritsch 2005).

The entering of regional networks as a focal point of the national research and innovation policy rooted in the increased perception of innovative activities exhibiting a strong regional component and that embeddedness in networks is crucial to firms' innovativeness and competitiveness. Thus, theoretical concepts that account for the regional character of innovation, such as the cluster approach (Porter 1998) or the idea of the regional innovation system (Cooke & Morgan 1994, Braczyk et al. 1998), constitute the rationale for modern innovation policy.

Since the end of the 19<sup>th</sup> century, scholars theorize on the economic benefits that arise for firms locating in geographic agglomerations of related industries (Marshall, 1890, Porter, 1998). In addition, several empirical studies provide evidence on the effects of co-location on innovation (Audretsch & Feldman 1996, Baptista & Swann 1998, Beaudry & Breschi 2003, Aharonson et al. 2008, Lecocq et al. 2009).

The reasons for clustering are manifold. Theorists argue that firms in clusters exploit the advantages of low transaction costs as they are located close to specialized suppliers and clients and have access to a specialized labor pool or are exposed to competitive pressure which drives profitability (e.g. Porter 1998). Furthermore, the proximity to scientific institutions and firms within the same or related industries results in the existence of a common knowledge spillover pool. Nevertheless, spatial proximity per se is neither a necessary nor a sufficient condition for knowledge spillovers (Giuliani 2007, Breschi & Lissoni 2009). The exploitation of existing innovation potentials in certain regions and the efficiency of the regional innovation system depends heavily on the degree of networking among regional actors (Koschatzky 2000, Sternberg 2000, Fritsch & Eickelpasch 2005).

Innovations develop during a collective learning process of several actors in which common knowledge generation, accumulation and diffusion are crucial ingredients (Asheim & Gertler 2006). Especially in the early stages of technology development, when knowledge is specific and complex, continuous communication and face-to-face contacts are indispensable for the efficient transmission of knowledge (Breschi & Lissoni 2001, Feldman 1994). The ease and costs of linkages and knowledge exchange are in turn related to the geographical distance of the correspondent actors. Moreover, spatial proximity allows for the development of trustful relationships and decreases the social distance among related actors (Boschma 2005). Hence, a firm's integration into the regional innovation network providing access to external knowledge sources is a crucial determinant of the firm's learning process and resulting innovative capabilities (Koschatzky 2000).

Although these insights constitute the core rationale for regional cluster policies fostering joint R&D projects, potential gains from clustering do not suffice as a legitimization for political intervention. According to economic welfare theory, political interference is justified when the market coordination mechanisms are not able to result in efficient/optimal outcomes. Evolutionary economists complement these classical arguments by pinpointing to the existence of system failures. Related to this view, the malfunctioning or ineffectiveness of innovation systems provides a reason for political action. Particularly, the presence of network failures in the sense of a deficiency of an optimal degree of linkages among actors in the innovation system formulates a rationale for cluster policies (Andersson et al. 2004, Carlsson und Jacobson 1997). Hence, the declared aim of the current German cluster policy, the “Leading-Edge Cluster Competition” (LECC) and related programs is the generation of value added for the region and for the national economy by stimulating the creation of regional networks.

With the expiration of the early pioneer programs and the subsequent introduction of new expanded instruments, such as the LECC in Germany, one major question arises: Does the public promotion of clusters actually provide an efficient measure to achieve the defined goals? Evaluations of cluster policies were introduced to answer this question. The purpose is to analyze the surplus for the region and economy that is attributable to the funding measure. Due to the long term character of these effects and the infancy of evaluation concepts, quantitative impact studies on cluster policies are relatively rare (Giuliani & Pietrobelli 2011). In addition, the few existing analyses provide ambiguous results. Martin et al. (2011) evaluate the impact of cluster policy on certain firm variables (for instance production and employment) and find no robust effects compared to non-funded firms. In fact, the policy measure which was included in their examination, the French “Local Productive Systems” program, focused rather on the idea of the industrial districts and merely interfirm collaboration than on the concept of the regional innovation system. Nishimura & Okamuro (2009) find that mere participation in the Japanese Industrial Cluster Project has no significant effect on the R&D productivity of firms. Only if cluster participants collaborate with national universities in the same cluster region positive effects were observed.

The focal point of further studies was rather the administrative process of cluster programs than the observable impacts. As for instance Fortagné et al. (2010) analyze the selection process of the subsequent French Cluster Policy “Competitiveness Poles” and find that mainly strong clusters were picked.

Furthermore, counterfactual analyses of cluster funding programs in Germany have shown that the success of BioRegio and related programs is grounded above all on the mobilization of long-term cooperations which would have not been existent without the program. In this process, primarily collaborations between firms and research institutions were initiated (Staebler et al. 2007). Similar results were obtained by Falck et al. (2010), who find that firms in targeted industries of a regional cluster initiative are more likely to become innovators despite a reduction of their R&D expenditures.

The present paper serves two purposes: First, it contributes to the discussion and adds to the rare empirical evidence on the impacts of cluster policies. Second, this paper is the first one which analyses the effects of a certain cluster policy, namely the German LECC, on the linkages and the related network structure in selected clusters by means of social network analysis (SNA). To our knowledge, there have been few attempts to apply SNA in the context of political evaluation so far (see Giuliani and Pietrobelli 2011 for a review).

We proceed as follows. In section 2 we briefly introduce the concept and objectives of the Leading-Edge Cluster Competition. Our research methodology, focusing on the network aspect of the LECC, is described in section 3. We present first results in section 4 and conclude in section 5.

## **2. The Leading Edge Cluster Competition**

In 2007 the German ministry for education and research (BMBF) followed up previous successful devices by launching the LECC, an initiative that aims at strengthening Germany's innovation potential and economic success by means of promoting regional clusters. The support of "Leading Edge Clusters" should result in the exploitation of regional innovation potentials and finally in innovation and economic growth. The competition was open for all types of technologies and focused on the funding of clusters with the most promising strategies for future markets that have the potential to count among the "Leading Edge" in their respective industry (BMBF 2012).

Overall, 15 clusters were selected in three waves (2008, 2010, 2012), to be labeled as "Leading-Edge Clusters" and to be funded for a five-year period with up to 40 million Euro each. The selection was consigned to an independent jury of publicly renowned experts from industry and academia.

Moreover, an accompanying evaluation is conducted to monitor the achievement of the declared goals and to derive concrete recommendations for the advancement of the measurement. Therefore, timely evaluations, especially of innovative funding schemes, are a crucial learning mechanism for the adaptive policy maker (Metcalf 1995).

One main claim of the competition is the support of regional networks. The idea is that the creation of an innovative environment, including intensive R&D collaboration between research institutes and industry, should boost an eminent innovative performance that allows for reaching an international leading position. With the application of SNA, we are able to observe the underlying network structures in the selected clusters and the ramifications originated by political influence. This allows us to provide a hint whether first politically desired effects occurred.

## **3. Research Methodology**

Our empirical analysis is based on the original survey of actors (benefiting firms and public research organizations) of four clusters (labeled from A to D) that were chosen as "Leading-Edge

Clusters” in the first wave of the competition at the end of 2008.<sup>1</sup> The survey was conducted in late summer of 2011, almost three years after the announcement of the winning cluster regions of the first wave, to capture first effects on the network structure.

We construct R&D networks on the basis of survey data by means of a free recall method. Thereby, beneficiaries (firms and research institutes) of the first wave were asked to list the names and address of their ten (strategically) most important R&D cooperation partners. Additionally, we collected information on attributes of these linkages, namely the reason for the strategic importance of the link, and certain firm characteristics. Even though it is argued that the roster recall method is to be preferred (ter Wal & Boschma 2009, Giuliani & Pietrobelli 2011), we chose the free recall design for mainly two reasons. First, the generation of a fixed list of actors (roster) would have led to large differences in the size of the clusters (imposed by the empirical design), since the cluster managements define their boundaries in quite different ways (e.g. only funded actors, only formal members of the cluster association, all actors that somehow participate in cluster activities). Secondly, with a roster recall linkages to R&D partners who are not cluster actors could not be observed. However, such extra local (and extra cluster) linkages are of high relevance for cluster success (Bathelt et al. 2004). Our decision for the fixed choice approach in limiting the number of partners to the ten most important ones followed primarily two considerations. On the one hand the acquisition effort of sufficient data for the network analysis is still within the bounds of feasibility for the respondents. On the other hand, the focus on the most important R&D partners allows us to assume an equal weight of the mentioned linkages and prevents the overestimation of linkages with lower intensity.

To attribute the observed network dynamics to the influence of the cluster competition, the actors were explicitly asked, whether the mentioned relations have existed before 2007 (date of the announcement of the LECC and if they were initiated or intensified by the cluster initiative. Hence, our impact analysis relies on the comparison of the network structure before and after the policy started. In addition, all findings from the SNA were corroborated by the help of actors’ interviews.

## 4. Results

### 4.1 Actor structures

Describing the actor structures in the four clusters, we distinguish four groups. First, *beneficiaries* are those organizations that receive subsidies from the LECC. Second, those beneficiaries who replied to our survey are the *respondents*. Third, *actors* are all the nodes in the network, i.e. all respondents and all organizations that were named by the respondents. Fourth, *cluster actors* refer to those actors that are members of the respective cluster association. This group encompasses all beneficiaries but also organizations that receive no direct funding.

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<sup>1</sup> The response rate, especially of firms, in one cluster was too low for a meaningful analysis. For reasons of confidentiality, we have to refrain from characterizing the clusters in more detail. Even though the clusters differ with respect to technological specialization, age, and location, we cannot make use of this information in our analysis.

A first view at the composition of the networks of strategically important R&D partners in the four clusters (table 1) reveals that the network size as measured by the number of nodes (actors) varies between 44 (cluster B) and 97 (cluster C). Some of this variation can be attributed to the different number of respondents, which ranges from 12 (clusters B and D) to 17 (clusters A and C).

**Table 1:** Composition of the clusters and their networks of strategically important R&D partners

Cluster	A	B	C	D
(1) Beneficiaries: no. of organizations that received a questionnaire	24	19	33	35
(2) Respondents: no. of organizations that provided information about their R&D partners	17	12	17	12
Response rate (2)/(1)	71%	63%	52%	34%
(3) Actors: no. of nodes in the network	61	44	97	48
(4) Cluster actors: no. of nodes that are members of the cluster association	24	20	41	25
Share of actors located in cluster region	36,1%	50,0%	45,4%	47,9%
... in Germany	50,8%	20,5%	37,1%	47,9%
... in Europe	8,2%	11,4%	7,2%	4,2%
... outside Europe	4,9%	18,2%	10,3%	0,0%
Number of linkages	101	43	126	58
... into cluster region	53,5%	48,8%	55,6%	55,2%
... to Germany	38,6%	20,9%	31,0%	41,4%
... to Europe	5,0%	11,6%	5,6%	3,4%
... to outside of Europe	3,0%	18,6%	7,9%	0,0%

Regarding the regional distribution of actors, it can be seen that the majority is located within the cluster or national boundaries. Only a small fraction of actors is located outside Germany, with some differences between the clusters. The consideration of the distribution of linkages exposes an almost similar picture. Most of the linkages are directed into the cluster region, followed by national linkages. Nevertheless, the clusters display remarkable differences concerning the focus on intraregional linkages and the embeddedness in international networks. It is noticeable that while cluster B seems to find a number of R&D partners internationally, cluster D is almost exclusively cooperating on a regional and national scale.

#### 4.2 Network structure and effects of the “Leading-Edge Cluster Competition”

In table 2, structural indicators and their changes in the course of the LECC are presented; in figure A1 (appendix) network visualizations are displayed. To infer on the effect of the cluster policy, we



compare the measures for the network based on all reported linkages with those for the network consisting only of those linkages that were present before 2007 (when the LECC was announced). We have to acknowledge that this is only an artificial dynamism since we do not have the information about the most important R&D partners in 2007, but can only observe a subset of those that were active at that time, namely those that were still present at the time of the survey.

One of the first important findings from the network analysis is that the policy has a significant positive impact on the intensity of networking. On average, more than half (52.5 %) of the existing linkages were affected by the LECC in the sense of initiation or intensification, with a minimum of 42.9% in cluster C and a maximum of 65.3% in cluster A. The majority of these links (35.6 %) was initiated by the program, indicating a strong impact of the policy measure on networking. Accounting only for the linkages among respondents, network density (all active linkages divided by the number of possible linkages) increased in all four clusters (on average from 4.9% to 11.5%). In cluster C, the increase from 8.1% to 13.2% is the lowest in relative terms, indicating that the cluster was already well connected before participation. According to face-to-face interviews with some of the actors, this increase of linkages is mainly a consequence of the increased visibility of potential partners and synergy potential triggered by the LECC; i.e. the policy measure mitigates the problem of intermediation within the clusters (Cantner et al. 2011). Furthermore, new partners entered projects via reputational advice from already known partners. The newly established contacts were initiated with the expectation to cooperate in the long run and beyond the own core competences.

Besides this policy effect on the intensity of collaboration between actors, we also observe a structural change with respect to the concentration of partnerships on few central actors. Attributable to the public funding, the extent of the centralization (based on the indegree) (Freeman 1979) increases in three of the four clusters and on average from 4.4% to 8.8%. This suggests that the newly established ties are preferentially formed with actors who were already central before the clusters decided to participate in the competition.

The clusters exhibit certain differences concerning their interior network structure. Cluster A and C form in each case a connected network since their network consists of only one component. That is to say that each actor is directly or indirectly connected to the network. The remaining clusters display a more fragile network topology. Moreover, clusters A and D seem to be more concentrated on few central actors, while cluster B displays a less hierarchical structure. The average number of connections also shows some differences between the clusters. In cluster B, the average respondent named 3.6 important cooperation partners (outdegree) while in cluster C more than twice this number (7.4) was reported. The mean indegree tells us how often the average actor is being named as a R&D partner. In cluster B this measure is below one (0.98), indicating that some actors are not named at all (of course, these can only be respondents). The maximum is observed in cluster A, in which actors are named 1.66 times on average.

**Table 2:** Structural indicators for each network with and without political impact

Cluster	A	B	C	D	∅
Linkages initiated by cluster program	45.5%	41.9%	20.6%	34.5%	35.6%
Linkages intensified by cluster program	19.8%	11.6%	22.2%	13.8%	16.9%
Linkages initiated or intensified by cluster program	65.3%	53.5%	42.9%	48.3%	52.5%
Density (among respondents)	0.154	0.068	0.132	0.106	0.115
Density (among respondents before 2007)	0.063	0.023	0.081	0.030	0.049
Components (weak)	1	3	1	3	
Centralization (indegree)	0.141	0.024	0.081	0.104	0.088
Centralization (before 2007)	0.053	0.034	0.042	0.048	0.044
Mean outdegree (only respondents)	5.941	3.583	7.412	4.833	5.645
Mean indegree (whole network)	1.656	0.977	1.278	1.208	1.304

**Table 3:** Linkages affected by policy to cluster actors

	A	B	C	D
Share of policy initiated linkages to cluster actors	71.7%	66.7%	84.6%	90.0%
Share of policy intensified linkages to cluster actors	65.0%	80.0%	82.1%	75.0%

In table 3, we report the share of policy initiated (intensified) linkages to cluster actors in all policy initiated (intensified) linkages. For the induced (intensified) linkages, these shares range between 67 and 90% (65 and 82%), indicating that new cooperations are mainly established among cluster members. However, these figures also show that the cluster policy also mobilizes partnerships beyond the cluster boundaries.

In summary we find that the LECC has proven successful in meeting the objective to foster the networking activities in the regions. The basis for an intensified and broader knowledge transfer is founded, which may lead to a higher innovative performance of the system in the future.

### 4.3 Geographic reach

A plain direction of the political influence becomes evident when analyzing the regional reach of the cooperative links. Although certain cluster specificities in the regional focus of the ties exist (see table 1 and the discussion in 4.1), the overall picture reveals a concentration on regional and national linkages. When including the effects of the LECC into our analysis, we see that roughly 75 % of all linkages affected by policy are among local partners and 22 % with national partners. The respective shares presented in table 4, show that there are only small variations between the clusters.

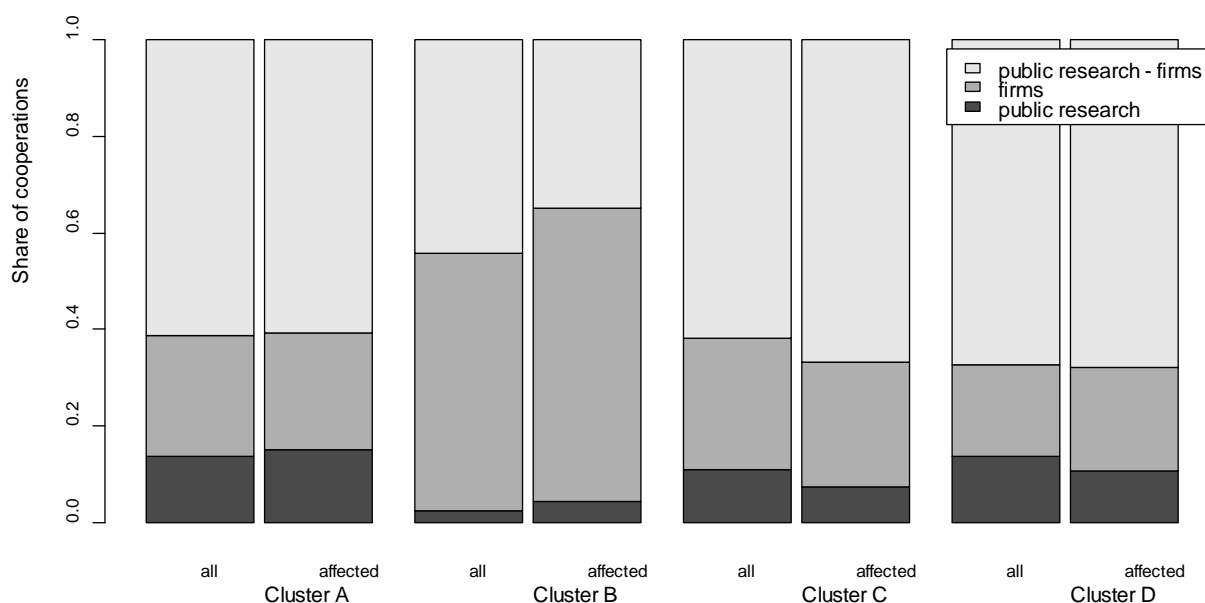
**Table 4:** Percentages of linkages affected by “Leading-Edge Cluster Competition” and their regional distribution

Cluster	A	B	C	D	Ø
Share of linkages initiated or intensified by cluster program	65.3%	53.5%	42.9%	48.3%	52.5%
Geographic reach thereof					
... into cluster region	68.2%	73.9%	77.8%	78.6%	74.6%
... to Germany	24.2%	21.7%	20.4%	21.4%	21.9%
... to Europe	4.5%	4.3%	1.9%	0.0%	2.7%
... to outside Europe	3.0%	0.0%	0.0%	0.0%	0.8%

Consequently, and corresponding to the declared aim of the policy, the LECC primarily stimulates local connections among actors and affects to a lower extent the creation of ties on a national and international level. Hence, in a first instance the LECC is effective in fostering intraregional networks.

### 4.4 Science-Industry interaction

Another important goal of the LECC is to connect industry and science to increase the speed of transfer of scientific discoveries into marketable products (BMBF 2012). Figure 1 shows the shares of all linkages within and between industry and science in the first bar for each cluster while the respective shares in the second bar are restricted to the linkages affected by the LECC. In three of the four clusters, research cooperations between firms and public research dominate. The connections that were influenced by the LECC show almost a similar pattern, which is actually quite surprising given the stated goal of the policy. Apparently, the motives to cooperate with specific partners are to be found in the regional and technological environment rather than in some (presumed) requirements stated by the policy maker.



**Figure 1:** Interaction between Science and Industry

#### 4.5 Relevance of linkages

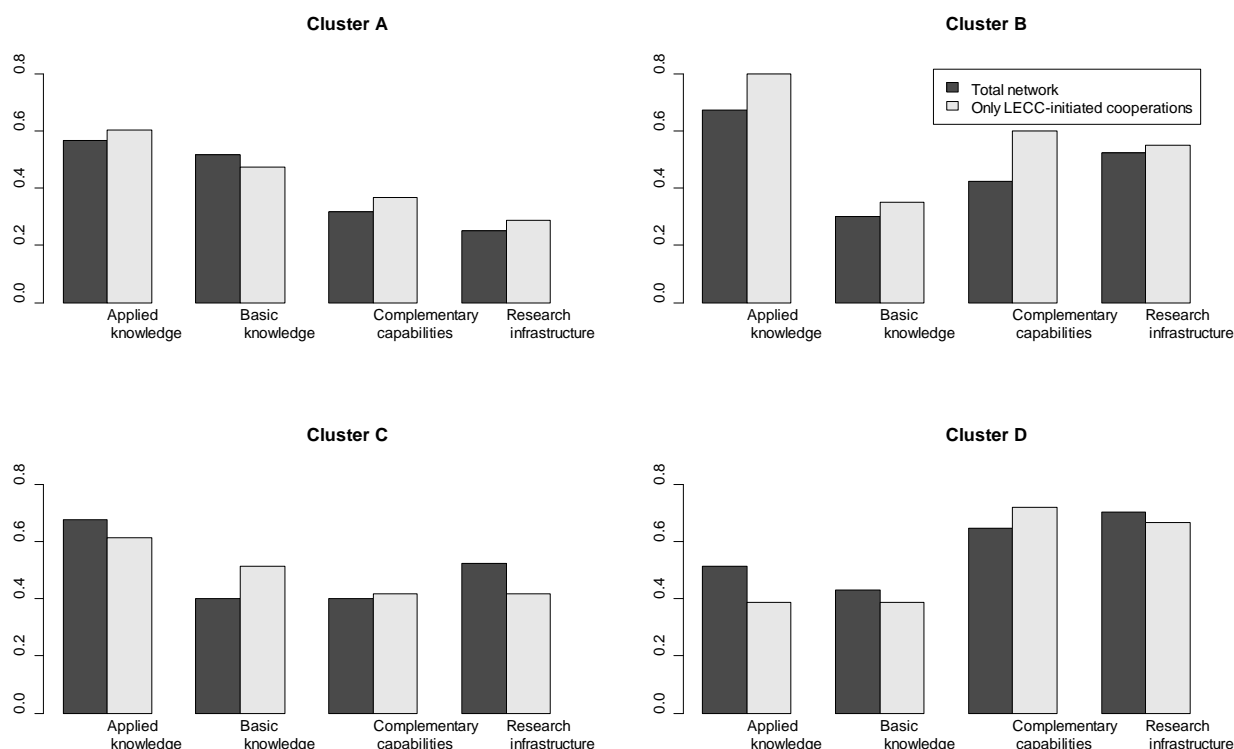
The formation of R&D cooperations is based on the expected benefits of both partners arising from collaborative activities. These benefits can arise in different ways depending on the type of strategies partners pursue. The type of strategic importance reflects the incentives of the partners to engage in this cooperation. Motives to cooperate are manifold: collaboration partners might be chosen as a valuable source “of applied knowledge” or “of basic knowledge”. In both cases, learning from the partners’ competencies is a central rationale for collaboration. Cooperations might also be formed because partners supply their specific capabilities to a common task, i.e. “complementary competences” are the source of strategic importance of a partnership. Partners might also be valuable because of their specific “research infrastructure” not present in firm’s own facilities.

To account for these different motives for partner choice, we asked the firms<sup>2</sup> to indicate, for each partnership, the motives that qualify it as strategically important. The responses are summarized in figure 2 for each cluster distinguishing between all partnerships (dark grey) and only those that were initiated by the cluster competition (light grey). This allows us to identify differences between clusters in their motivation to cooperate and also gives us the opportunity to observe any systematic deviations of policy induced linkages from the overall picture.

With respect to cluster specificities in the motives to cooperate, we observe some generalities but also some notable differences. First of all, access to sources of applied knowledge is, with one

<sup>2</sup>We did not ask the research institutes since the motives to cooperate differ between the private and the public sphere.

exception, the most important reason for the strategic importance of R&D collaborations. This is followed by the technical infrastructure that is available with the R&D partners. The acquisition of basic knowledge is especially important in cluster A, while complementary capabilities are of high importance in cluster D.



**Figure 2:** Reasons for strategic importance of R&D partners

In general, the policy induced linkages are not biased towards any of these motives. In cluster B, it seems that the LECC managed to bring together actors with complementary capabilities and strengthened the exchange of applied knowledge. In cluster C the acquisition of basic knowledge was reinforced. From an evaluation perspective, this result reflects the high flexibility of the policy measure since it is open for various types of partnerships.

## 5. Discussion and Conclusion

Policies aiming at the promotion of clusters are frequently conducted but only seldom evaluated (Martin & Sunley 2003, Brenner & Schlump 2011). The aim of this study was to add to our understanding of the effects and mechanisms of cluster policies by analyzing the impact of the German “Leading-Edge Cluster Competition” on the underlying network structure. Since the LECC is an ongoing initiative, we could only report intermediate effects on networking within the funded clusters. By means of Social Network Analysis on the basis of a carefully constructed questionnaire it was possible to identify effects on the network of strategically important R&D partners within the clusters that are attributable to the policy instrument.

Our results show a significant effect on the network structure in terms of density, centralization and geographical reach. Measures on structural effects in terms of number (breadth), weight (intensity) and distribution of linkages (centralization) indicate policy influences already three years after starting the funding.

First, on average more than half of the existing linkages were either initiated or intensified by the LECC with the consequence of an increased density of the network. Second, since the majority of these policy-affected linkages are within the cluster region, the LECC shifted the focus of collaboration towards local networking. While such an effect is quite natural for a cluster oriented policy, it is not to be judged without some skepticism. Experiences of a Japanese cluster initiative show that local firms have a higher R&D productivity if they collaborate with partners outside the cluster (Nishimura & Okamuro 2009). Moreover, path-dependencies for firms and regions which can lead to spatial lock-in in the long run inhere in the mere search for internal collaborations (Sternberg 2000). These concerns have also been brought up in the discussion on local buzz and global pipelines (Bathelt et al. 2004) and have been related to the stage of the cluster within its life-cycle by Brenner & Schlump (2011). They suggest that a network renewal by means of increased cluster external linkages is especially important in more mature phases of cluster development. Since the four clusters analyzed in this paper differ considerably with respect to age or maturity of technology, the dimension "stage in a cluster life cycle" requires further scrutiny.

A third result is concerned with the distribution of linkages within the networks. In three out of four cases the network becomes more centralized, i.e. it exhibits a stronger orientation towards a few, central actors. Interviews with selected beneficiaries in the clusters suggest that this development is rated particularly important for the integration of SMEs within the cluster. For small firms, which in general struggle with difficulties to get in contact with large firms, the LECC offers opportunities to connect to these; the firm representatives value these contacts of crucial importance for their long term integration into the network and finally their innovative performance. However, more centralized networks are also more vulnerable, since their dependence on the functioning of single actors is higher as compared to other network structures. With respect to the rate of knowledge diffusion, Cowan & Jonard (2004) could show that small world structures are the superior form of organization. The results of Schilling & Phelps (2007) on the structure of industry networks add to the difficulties in evaluating this development towards increased centralization. They find negative effects of network centralization on future patenting in the short run but positive effects in the long run.

Fourth, with respect to the interaction between science and industry, we find that the majority of connections that were affected by policy link firms with universities or research institutes. However, this was also the case for previously existing linkages, which implies that the LECC did not increase the relative frequency of science-industry linkages but rather duplicated existing structures and indicates that a functioning science-industry relationship was an important selection criterion of the clusters in the first place. We interpret this observation as a sign of flexibility of the policy measure which leaves the choices of partnership to the beneficiaries.

Overall, while we can state that the LECC has met its objective to intensify collaboration among innovative actors, our intermediate evaluation does not allow us to assume, that this will lead to a better performance of the selected clusters in the future. At this stage, we are also unable to provide evidence on correlations between the observed structural changes and the innovative performance of the cluster regions. Statements in this direction will require a subsequent long term analysis including comparisons to non-funded clusters.

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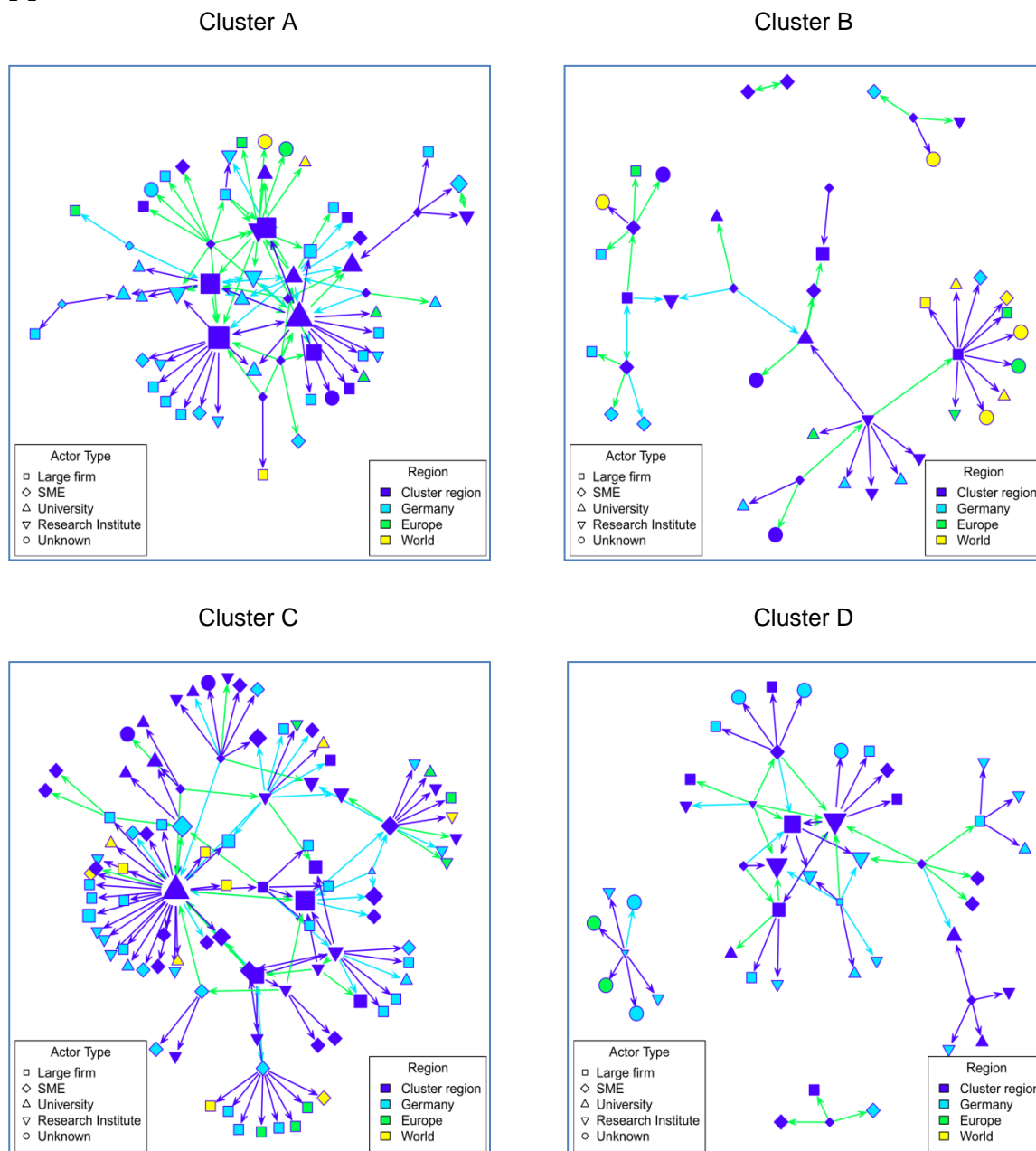
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Appendix



**Figure A1:** Networks of strategically important R&D partners in clusters A to D. Arrows indicate a partnership *from* the respondent *to* one of the most important R&D partners. Green arrows indicate that the partnership was initiated through participation in the "Leading-Edge Cluster competition", light blue arrows indicate that the partnership was intensified through the competition, and dark blue arrows indicate partnerships that were not influenced by the competition. Node size is proportional to indegree, i.e. to the frequency of being named as a partner. The colors and the shapes of the nodes indicate the actor's geographic location and type according to the legend.