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# Structural dynamics of innovation networks in German Leading-Edge Clusters

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## **Abstract**

We study the effects of a German national cluster policy on the structure of collaboration networks. The empirical analysis is based on original data that was collected in fall 2011 and late summer 2013 with cluster actors (firms and public research organizations) who received government funding. Our results show that over time the program was effective in initiating new cooperation between cluster actors and in intensifying existing linkages. Newly formed linkages are to a substantial amount among actors who did not receive direct funding for a joint R&D project, which indicates an additional, mobilisation effect of the policy. Furthermore, we observe differential developments regarding clusters' spatial embeddedness. Some clusters tend to increase their localisation, whereas others increase their connectivity to international partners. The centrality of large firms increased over time, indicating their prominent role as preferred partners for R&D cooperation within the clusters while it is the opposite case for public actors.

**Keywords:** Cluster, Innovation Policy, Evaluation, Social Network Analysis

**JEL Codes:** O38, L14, R10

## **1 Introduction**

Over the last decades a distinctive shift in innovation policy in Germany and many other countries towards an increased funding of cooperative R&D was observable (Fier and Harhoff 2002). In the past years, competitive allocation of research funds to network and cluster 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. Prominent examples of these policies in Germany are the competitive programs BioRegio and InnoRegio (Dohse 2000; Eickelpasch and Fritsch 2005; Engel et al. 2013). In the context of its high-tech strategy the German ministry for education and research (BMBF) started the “Leading-Edge Cluster competition” (LECC) (Spitzencluster-Wettbewerb) in 2007. The conceptual foundation of this and related policies is mainly to be found in the literature on clusters, but also on regional innovation systems and innovation networks. At the core of the LECC is the funding of R&D cooperation within concrete projects and pools of joint R&D projects on a specific topic or problem with high innovation opportunities. From a network perspective, this policy approach aims at establishing new linkages (initiated linkages) or strengthening existing ones (intensified linkages) of R&D-cooperation networks.

As yet, empirical validations of the benefits of the policy impact on the process of cluster formation, development, and success are (more than) sparse (Martin and Sunley 2003; Duranton 2011). Since evaluations, especially of innovative funding schemes, are crucial for learning of the adaptive policy maker (Metcalf 1995) there is obviously a need for such kind of an empirical analysis. Following the suggestions of Giuliani and Pietrobelli (2011) and building on the previous analysis by Cantner et al. (2013), we employ social network analysis to study the influence of the LECC on interaction structures. Our goal is to identify to which extent the LECC influences the structure of the network of the most important R&D-cooperation partners within the funded clusters. This impact can appear directly through the funding of joint research projects or indirectly through a mobilisation effect of the policy representing an additional value besides the research grants. Therefore we focus especially on R&D-cooperation and the corresponding networks covering various kinds of actors engaged in R&D and innovation processes such as firms, research institutes and universities within and outside of the funded cluster. Our analysis does not explicitly consider the specifics of bilateral cooperation but focusses on the general embeddedness of network actors into the network to identify especially the structural effects of the policy.

The paper is structured as follows: section 2 covers the theoretical background for our analysis as well as some general description of the LECC. In section 3 we introduce our data and research setup and in section 4 we present our results concerning the impact of the LECC on the structure of R&D cooperation networks. In section 5 we move to the micro level and study changes of network positions due to the LECC. Section 6 concludes.

## **2 R&D cooperation and the “Leading-Edge Cluster Competition”**

### **2.1 Rationale for cluster policies**

Due to the increasing complexity of new knowledge, outsourcing of specialized tasks within the knowledge creation process has become more and more important (Chatterji 1996). Therefore, the level of openness and the distribution of tasks within the knowledge and innovation generation process have increased over the last years (Coombs et al. 2003). The positive effect of cooperation, networking and interconnectedness on the innovative success of innovation oriented actors has been shown by many authors (Freeman 1991; Lundvall 1992; Cantner and Graf 2006; Schilling, Phelps 2007; Breschi and Lissoni 2009; Cantner et al. 2010; Graf and Krüger 2011). Such cooperation can be bilateral – between two partners – or multilateral – between a group of actors trying to solve a general or concrete (technological) problem together as a kind of formal or informal research consortium or simply as joint research project. An active participation in innovation related networks can be an important mechanism for firms as well as for research institutes and universities to gain access to external knowledge sources. On the one hand it fosters the creation of new knowledge via the exchange of knowledge and information and by combining complementary capabilities (Granovetter 1973; Ahuja, 2000) and on the other hand it provides a possibility for monitoring and controlling actual developed knowledge (Powell et al. 1996). The diffusion of knowledge is accomplished via different transmission channels, such as joint activities within formal industrial networks or clusters, through joint R&D projects or simply through informal contacts between employees/researchers of different firms, universities or research institutes (Cowan and Jonard 2009).

There is a positive correlation between a central position within a network and innovative success due to better direct and indirect access to different sources of knowledge (Ahuja 2000; Schilling and Phelps 2007). Furthermore, the structure of a network influences the communication and the knowledge flows within all involved actors and has an effect on the general availability of knowledge and thereby on the innovative success (Cowan and Jonard 2004; Fleming et al. 2007). However, it is very difficult to state

which specific structure of a network fosters innovation since the correlation between network structure and innovation strongly depends on the innovative environment (Rowley et al. 2000; Verspagen and Duysters 2004). Nevertheless, Fleming et al. (2007) and Schilling and Phelps (2007) suggest that network connectedness – characterized by high density or few components – and medium centralization affect the performance of networks positively. While centralization fosters communication and the speed of knowledge diffusion, it can also indicate a high dependence on single actors and leads to an unequal knowledge distribution.

Becker and Dietz (2004), amongst others, show that joint R&D enhances the realization of innovation. A lack of cooperation could therefore be interpreted as a system failure in which possibilities for improving innovative performance of an industry or a cluster remain unexploited. In case of such a system failure, policy interventions in the form of promoting joint R&D activities can help to overcome this problem and increase innovative activities. The success of such policies depends last but not least on actor characteristics. In the literature on absorptive capacity the role of the own knowledge stock to be able to understand and to implement external knowledge has been widely discussed (Boschma and Wal 2007). The same holds also for R&D cooperations, which are according to Gomes-Casseres et al. (2006) the most important source for accessing external knowledge. Miotti and Sachwald (2003) argue that for successful cooperation in general firm's characteristics are more important than a specific cooperation that is publicly promoted and Boschma (2005) rules out the importance of (social) proximity between actors to create a "climate of trust" that foster collaboration. Consequently it is not sufficient for a policy that tries to stimulate cooperation within a cluster or a region to promote joint R&D activities but it also needs some mechanism to help actors to find the right and fitting partners. Duranton (2011) points out that cluster policies need to solve coordination problems among the involved actors and therefore create safety in a highly uncertain world without being captured by any group of interests. If policies fail in this respect, expected productivity gains will not occur as observed in the case of the French cluster policy "Systèmes Productifs Locaux" (Martin et al. 2011).

## **2.2 Leading-Edge Cluster Competition**

As a follow up to competitive policy programs in Germany, such as BioRegio and InnoRegio, the German ministry for education and research (BMBF) started the LECC in 2007 as one prominent instrument within its high-tech strategy. The aim of this program is to strengthen innovative capabilities and to support highly productive and efficient regional clusters to achieve or to maintain international leadership. Hence, regional innovative capacities should be exploited via innovations leading in the end

to economic growth. To address these targets, different opportunities had been established to create an innovative environment or to increase innovative performance inside a region due to intensified R&D cooperation between different actors like firms, research institutes and universities.

Within this program, 15 clusters were selected in three waves (in 2008, 2010 and 2012) and received a funding of up to 40 million Euro each for a five-year period. The funding was split into two phases – 20 million Euro each – where the allocation of the second one depends on a positive evaluation of the achievements of the cluster and the success of the realised projects herein after two years. The competition was open to all technologies and the selection of successful clusters was consigned to an independent jury of renowned experts from industry and academia. In order to foster the innovative success of the clusters the BMBF formulated several requirements. The following two are in our opinion the most important ones: First, the applying clusters needed to have a cluster management coordinating to some extent the activities within the cluster. This management also serves as intermediary between cluster actors, linking those with complementary competencies. As such, the LECC implements the function of local coordination among cluster actors as suggested by Duranton (2011). The stimulation of an additional goal of the LECC – to link scientific and economic actors – could be increased through this institution. To increase the quality of the project portfolio the cluster applied for funding with, these cluster managements organised together with a committee of actors a preselection of projects. Furthermore in most of the funded clusters these managements offer also additional services to the cluster partners. Second, a common strategy linking the different R&D project proposals to one vision for the whole cluster and cluster region was required. A broad commitment to this strategy could be achieved by establishing a formal cluster organisation in which all potentially funded actors participate. At the same time social proximity among the cluster actors increased through this shared membership and commitment to the strategy. Therefore an increased probability for cooperation and also innovative success could be expected (Boschma 2005). The abandonment of the LECC to strict regimentation regarding cluster organisation and composition of actors led to a large heterogeneity between the clusters in terms of technological focus, formal structure and existing boards, as well as the set of activities within the clusters and their managements. But also the size of their geographical areas and distances within cluster boundaries differ substantially due to the open interpretation of the cluster concept.

### **3 Data, Methodology and Variables**

Our analyses are based on primary data collected with members (firms, universities and research organizations) of the five successful clusters of the first wave of the LECC (in 2008) which all also received funding for the second period. We study the networks of most important cooperation partners and focus on their actor composition as well as their geographic reach. Structural changes of these networks are considered and the presumed policy influence is investigated. Since the LECC initiative was open to all kinds of technologies, our sample clusters differ quite substantially. The cluster “BioRN” is active in the field of red biotechnology – and therefore many actors can be assigned to the pharmaceutical industry supplemented by knowledge intensive services from life science and software development. Due to this composition, small-or-medium-sized enterprises (SMEs) are the majority of cluster actors in BioRN. However, large pharmaceutical companies play an important role as the main costumers of innovative SMEs. The reason for this is the difficulty to transform from an SEBCO (Small Emerging Biopharmaceutical Company) into an FIBCO (Fully Integrated Biopharmaceutical Company) due to heavily increasing costs during later stages of R&D projects. Therefore, large firms often take over their projects via licencing or even the whole SME. The cluster “Cool Silicon” focuses on increased energy efficiency in microelectronics. Consequently, cluster actors are related to electronic semiconductors and electronic devices but also medical technology and industrial process and control technology. Additional knowledge intensive services are related to engineering and software development. In contrast to other large IT-clusters like the Silicon Valley in the USA, R&D activities and productive activities are not decoupled. The technological core of the cluster “Solarvalley” is silicon based photovoltaic but also the thin film technology is present. Its value chain is closely related to the semiconductor industry, that is why cluster actors focus, as in Cool Silicon, on electronic semiconductors and electronic devices but also on fine mechanical optical devices, mechanical testing machinery and production of optical instruments. The joint aspect of this cluster at its origin was the vision to achieve grid parity in 2015. For that reason, R&D activities within the cluster have a strong application-orientation with a focus the accuracy of fit along the value creation chain. “Hamburg Aviation” combines two aspects of the aviation industry. First, there are activities related to aerospace technology and engineering, especially development, construction and production of cabin systems together with innovative applications for fuel cells. Second, a many actors cover a broad spectrum of services related to aeronautical technics and air traffic. Besides a few large anchor companies as well as several research institutes and universities, the cluster includes a notable number of SMEs. The technological focus of the cluster members is much broader than the cluster concept and covers a heterogeneous field of knowledge intensive services from natural

science to software development. The main focus of the last cluster in our sample – “Forum Organic Electronics” (FOE) – is the cross-sectional technology organic electronics, which offers a wide range of potential applications for the processing industry. The actors mainly focus on more advanced and high tech applications of this young technology. Due to the novelty of the technology and a strong focus on basic research, the composition of cluster actors is dominated by large companies as well as renowned research institutes and universities. The number of small-or-medium-sized enterprises in comparison to the other four clusters is relative low. Within “FOE”, the cluster actors concentrate their R&D activities on organic LED, organic photovoltaic, organic sensors and organic memories and circuits.

The data for our empirical analysis was collected in fall 2011 and late summer 2013 in the form of questionnaires sent to representatives of the cluster actors who received a government grant within the cluster initiative. For the reconstruction of the networks, these actors were asked to provide the names and addresses of up to ten of their most important R&D-partners. In addition, we asked the respondents to provide supplementary information regarding the properties of these linkages. Most importantly, we asked if the partnership was initiated by the LECC, if it existed before the contest was started in September 2007 and if in that case the linkage was intensified through the LECC. Furthermore, we asked for typical characteristics of the organization. To complement our data, we conducted several interviews with different actors to obtain qualitative insights on the clusters.

For the questionnaire, we chose a free recall design for several reasons. First, we wanted to avoid a strict limitation in the size of the networks that would result if we had presented a list of potential partners, i.e. cluster actors. In addition, this list would have been based on information provided by the respective cluster management and the governmental project management. However, both apply different definitions of the respective clusters which would have led to biases in the geographical and technological demarcation of the clusters and associated problems in comparing the clusters. Second, with a predefined list of actors, we would not have been able to identify linkages with partners that are not members of the cluster. However, since these external linkages – often with more geographically distant partners – are highly relevant for innovative success (Bathelt et al. 2004), the information about partnerships with these external actors is crucial for evaluating the effects of the LECC on the network structures. Finally, a predefined list of actors filled with cluster members would have biased responses towards these actors, even if we would have allowed for adding important R&D-partners to this list.

Table 1 delivers a summary of the data with respect to the total number of identified nodes within all networks, the composition of networks in terms of actor type (large company, small-or-medium-sized



enterprise (SME), university, or research institute) and the geographical dimension of actors and linkages. The data for 2007 is based on our survey in 2011 and covers all nodes and linkages that have been reported as existing already before the beginning of the LECC – if the cooperation already was established before September 2007. Therefore the response rate for 2007 and 2011 are identical and 2007 is to be viewed as a subset of the “true” 2011 network.

**Table 1: Description of the dataset**

	total sample (all clusters)		
	2007	2011	2013
Sample size (beneficiaries)	136	136	178
Number of responses (related to network question)	65	65	94
...large companies	16	16	21
...SME	29	29	29
...Universities	10	10	11
...Research institutes	10	10	18
Response rate (item related)	47.8%	47.8%	52.8%
Actors: no. of nodes	188	285	319
Cluster members: no. of nodes being member of the cluster association	101	132	135
Actor located in cluster region	49.5%	45.3%	41.7%
... in Germany	39.4%	38.6%	39.5%
... in Europe	6.9%	7.7%	8.5%
... outside Europe	4.3%	8.4%	9.1%
Number of linkages	171	380	463
... into cluster region	49.7%	55.5%	55.5%
... to Germany	38.0%	32.4%	31.5%
... to Europe	7.6%	5.8%	5.8%
... to outside Europe	4.7%	6.3%	6.3%

Our sample consists of two different types of actors, those that are part of the formal cluster organization/association and those without a formal membership. The former are defined as having received funding within the LECC. However, not all of them are respondents in our sample. If they chose not to provide answers to our questionnaire, they can still appear within the networks if named as an important partner for at least one of the respondents. While cluster members are typically but not exclusively located within the cluster region, the overall networks are geographically more dispersed. Still, the majority of all actors are located inside the cluster region or inside Germany and only 11.2% (in 2007) to 17.6% (in 2013) are international collaboration partners. R&D cooperation with partners inside

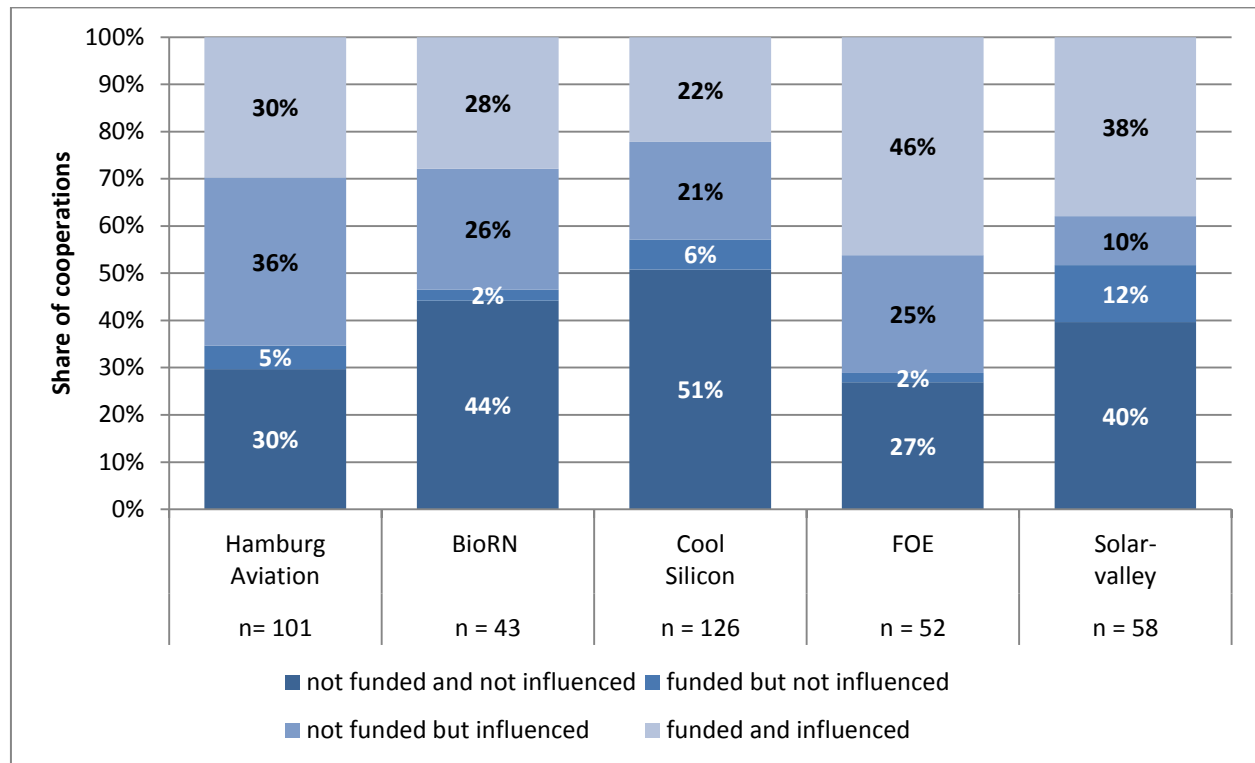
the cluster region account for roughly half of all linkages, those with partners inside Germany make up one third, and only a small fraction is related to a region outside Germany. Since we collected our data from actors that are mostly located inside the cluster region this pattern of the geographical distribution of linkages is not surprising and the interviews with funded actors confirmed that they prefer geographically close partners. Also Feldman (1999) and Boschma (2005) point out, that geographical proximity is an important determinant for successful cooperation that fosters the innovative and economic success of a cluster. Only if no competent partners reside within the cluster region, actors cooperate with external partners, and search rather national than international. Nevertheless roughly 50% of the strategically important R&D partners are not located inside the core region of the cluster. The linkages to these actors provide access to external knowledge hubs complementing the available knowledge inside the cluster and, as Bathelt et al. (2004) point out, these external partners are important sources of knowledge fostering the innovative success of a cluster. Without these external linkages a cluster would face the danger of a regional lock-in (Bathelt et al. 2004, Boschma 2005). Slight differences between the clusters regarding the geographical distribution of linkages, as shown by Cantner et al. (2013), are due to peculiarities of the technological systems the clusters belong to but will not be further explored here.

#### **4 Influence of the LECC on R&D networks**

To identify the general impact of the LECC on clusters' R&D networks, we rely on two attributes of the linkages. We know if reported linkages are also funded by the LECC and if they are perceived to be influenced by the LECC. These two dimensions lead to four classes of linkages, namely "not funded and not influenced", "funded but not influenced", "not funded but influenced", and "funded and influenced". We draw the information on funded versus not funded partnerships from data provided directly by the BMBF and partially from the publicly available database "foerderkatalog.de" about R&D project funding of the German government. The information on LECC influence is based on a self-assessment within our survey, where respondents were asked to provide additional information for each of their strategic R&D cooperations. A cooperation is influenced, if it was reported to be either intensified or initiated through the LECC.

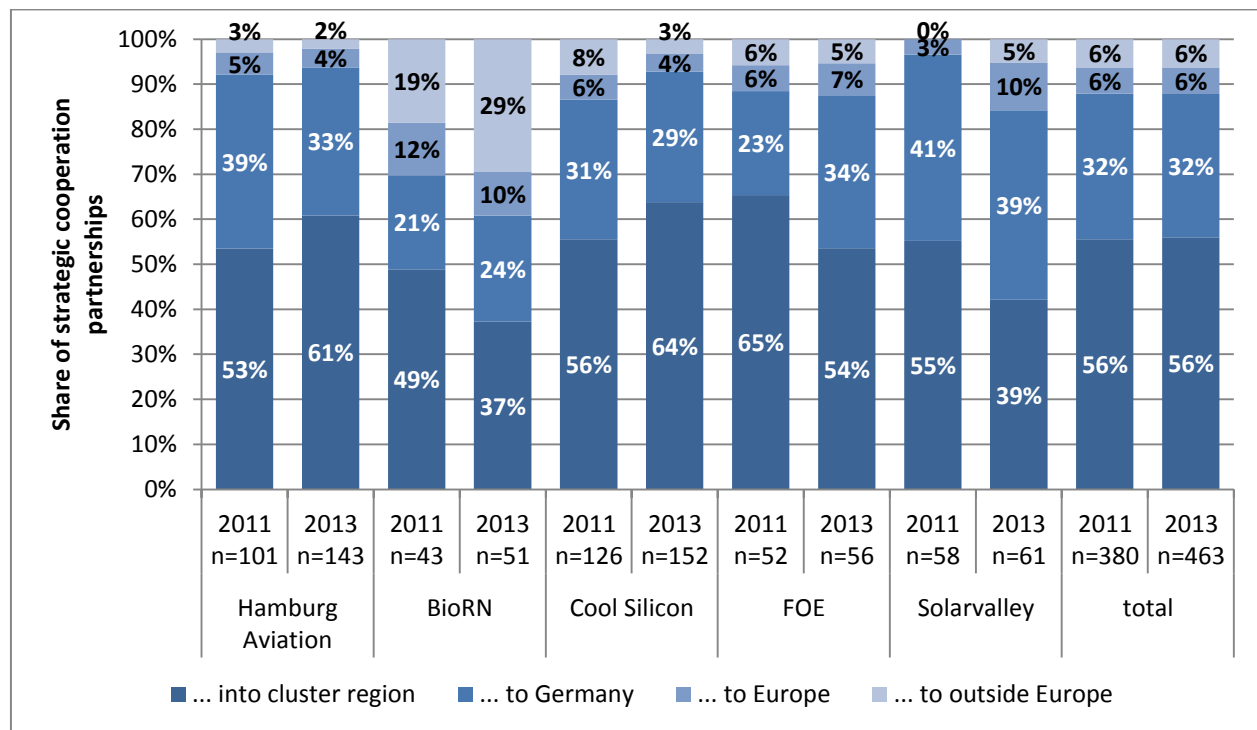
Figure 1 illustrates for 2011 that the establishment of new linkages and the intensification of existing ones occurs not only via funded joint research projects. A mobilisation effect of the LECC can be assumed for those linkages that are either intensified or initiated but did not receive public funds for a

collaborative project. The share of these partnerships ranges between 10% and 36%, which shows that beside the direct effects of the policy – the funding of concrete joint R&D projects – a non-negligible indirect impact exists. One reason for these indirect effects could be the common membership in a funded cluster and the related commitment to a joint strategy of the whole cluster – which is one of the specific attributes of the LECC. Cluster membership increases the visibility of actors and their expertise and new potential partnerships among cluster actors are exploited. At the same time the accessibility of prominent actors improved, allowing small and more peripheral actors to cooperate with these prominent ones. This was the case in Hamburg Aviation the cluster with the largest mobilisation effect, where during the process of cluster formation the openness for new cooperations of the established, large companies such as “Airbus” or “Lufthansa Technik” increased. During our interviews representatives of SMEs confirmed that thanks to the cluster creation process it was much easier to meet these large companies at eye level which fostered the formation of cooperations with them. Simultaneously, with the development of the joint cluster strategy, missing competences among cluster actors could be identified and as a result of the subsequent partner search, new partnerships could be established to remedy this shortage. Nevertheless, we also observe the opposite case of what might be called free-riding – funded but not intensified linkages – but on a lower level (2% to 12%). The largest share of free-riding (12%) was reported from Solarvalley. This fact is not surprising for the photovoltaic industry since secrecy was reported during our interviews as the main strategy to protect newly gained knowledge. Consequently, trust among partners was a dominant precondition for cooperation – especially in the field of R&D. Therefore a reasonable share of LECC funded joint projects was between actors that had already established partnerships through former cooperations. The prosperous establishment of a new partnership happened mostly through a third, well-known cooperation partner, who already cooperated successfully with the unknown partner. The net effect of mobilisation and free-riding for the R&D cooperation networks remains positive in all clusters except one (Solarvalley).

**Figure 1 Impact of the Leading-Edge Cluster Competition on strategic cooperation in 2011**

n: number of linkages

The geographical extent of the networks differs among the clusters and we also observe different trends during the time of funding through the LECC (figure 2). First, there are Hamburg Aviation and Cool Silicon which tend to localize with an increased share of linkages into the cluster region. Apparently, the LECC helped both clusters to discover and exploit additional regional capacities. Second, BioRN and Solarvalley become more internationally orientated. For Solarvalley, this trend can be explained by the fundamental changes of the market environment and the corresponding strategy change of the cluster during this phase. Last, there is FOE, where local linkages decrease in favor of a stronger national focus. Interestingly, the geographical composition within the whole sample of observed network nodes does not change from 2011 to 2013 even if the total amount of actors increased. This means that an assessment based on aggregate statistics, ignoring cluster specific developments, might well lead to wrong conclusions regarding the effects of cluster policies.

**Figure 2: Geographical distribution of most important R&D partnerships**

n: number of linkages

For an additional analysis, we distinguish the influenced linkages as intensified or initiated. The former are defined as linkages that already existed before the LECC and are influenced by the LECC; the latter are linkages that were reported to have been established because of participating in the LECC. The first three rows of table 2 show for each cluster that a substantial share of the identified linkages has been influenced by the LECC, either as being intensified or being initiated. Especially in Hamburg Aviation and FOE more than the 50% of all linkages, which existed already before the introduction of the LECC in 2007, were intensified by the policy. Based on our interviews, we know for FOE that due to its technological newness there was only a limited number of competent actors in the field of organic electronics in the cluster region. Most of them knew each other already before the beginning of the LECC but thanks to the design of the policy with its requirement of a joint strategy, these actors increased the level of cooperation to foster the development of organic electronics. In the other three clusters, one third of the existing links in 2007 were intensified by the LECC. This overall high share of strategic R&D cooperation which was intensified by the cluster policy reflects a first, short run impact of the policy. In these cases, already existing structures of the network of strategic important R&D cooperation were strengthened due to the introduction of the policy. The influence of the LECC on the network changes over time. In 2011, the influence is mainly via new partnerships (initiated) whereas the strengthening of

existing linkages (intensified) is relatively more frequent in 2013. In addition to that, we report in table 2 the network density among respondents, the indegree centralization based on the whole sample of linkages and the indegree centralization without the initiated linkages. For the period 2007 to 2011 we observe an increase in network density (realized linkages divided by all possible linkages). This fact shows the increasing interconnectedness between the funded actors. Considering the observations in 2013, an increasing network density seems to be sustained at least for the Hamburg Aviation, Cool Silicon and FOE. Here the increase in interconnectedness remains stable over the time of governmental funding. For the Solarvalley the extensive economic changes within the photovoltaic industry may be an explanation why the increase of network density during the first period of the LECC doesn't remain stable for 2013. On the one hand due to the change of the market environment the relevance of former important partners may have changed and on the other hand there was a non-negligible shake out of actors with a negative influence on the availability of partners.

All five case study clusters are centred around one or more prominent global players and/or an excellent research institute or university. As such, observing a moderate or high degree of network centralization is no surprise. However, ex ante it is unclear in which way the LECC influences the network structure in terms of centralization. If peripheral actors grab the opportunity to connect with the more prominent central actors, we would observe an increase in centralization, whereas if peripheral actors learn about each other and become aware of their complementary capabilities, centralization should decrease. We decided to calculate network centralization based on actors' indegree which is independent of own responses to avoid distortions from the fact that not all actors answered to our questionnaire. We observe an increasing centralization in all but one network during the funding period from 2011 to 2013. This result also holds if we calculate centralization without links that were initiated by the LECC. That means that each network, with exception of Solarvalley, tends to increasingly focus on the network core. These actors mostly play a prominent role inside the technological field of the cluster but also within the associated cluster organization. For Solarvalley the special situation of the PV-industry in general and especially in Germany might explain this different development. Some of the large actors in this cluster either left the market or have been taken over by Asian investors and therefore lost – according to our interviews – attractiveness for R&D partnerships due to the fear of unintended knowledge spillovers.

**Table 2: Influence of the Leading-Edge Cluster Competition on network structures**

	Hamburg Aviation			BioRN			Cool Silicon			FOE			Solarvalley		
	2007	2011	2013	2007	2011	2013	2007	2011	2013	2007	2011	2013	2007	2011	2013
Initiated linkages by LECC	-	45.5%	25.9%	-	41.9%	27.5%	-	20.6%	27.6%	-	53.8%	35.7%	-	34.5%	19.7%
Intensified linkages by LECC	55.6%	19.8%	35.0%	29.4%	11.6%	17.6%	37.3%	22.2%	36.8%	52.9%	17.3%	17.9%	30.8%	13.8%	42.6%
Initiated or intensified linkages by LECC	55.6%	65.3%	60.8%	29.4%	53.5%	45.1%	37.3%	42.9%	64.5%	52.9%	71.2%	53.6%	30.8%	48.3%	62.3%
Density (related to respondent)	0.040	0.154	0.132	0.023	0.068	0.038	0.070	0.132	0.155	0.000	0.167	0.133	0.015	0.106	0.027
Centralization (indegree)	0.056	0.141	0.173	0.057	0.024	0.082	0.058	0.081	0.153	0.115	0.106	0.163	0.073	0.104	0.052
Centralization without initiated linkages	-	0.053	0.130	-	0.034	0.046	-	0.042	0.124	-	0.070	0.090	-	0.048	0.056

## **5 The development of R&D networks during the LECC**

The increase in network centralization indicates that potential knowledge flows become more concentrated and that some actors benefit more than others from the policy. Consequently, we ask how actors that become more central are characterized to study the selective nature of the LECC. Considering that almost all policies – and especially those that are picking winners – create distortions, it is important to understand the structural changes on a micro-level. Therefore we proceed to analyze the structural specificities and changes of the R&D networks of the clusters during the LECC, based on a balanced panel of actors that are observed in 2011 and 2013. This restricted dataset leaves us with observations for 142 actors. On this basis, we analyze changes in their indegree centrality between 2011 and 2013, with a special focus on the policy influence.

In our econometric analysis, we employ the following variables (table 3): The dependent variable is the change of an actor's indegree centrality from 2011 to 2013 ( $d.deg$ ). Our main explanatory variables that measure a direct policy impact refer explicitly to funding within the LECC. We use information on the number of funded projects in 2013 ( $num.proj$ ) and the natural logarithm of the total amount of funding for the second period of the LECC (2013) ( $log.fin$ ). To control for non-linearity in the funding variable, we also use the squared term ( $log.fin^2$ ). To control for additional actor characteristics, we distinguish between types of actors, namely whether they are formal members of the respective cluster ( $cluster.actor$ ) and whether they are private or public organizations ( $public$ ). Size is taken into account by a dummy variable ( $actor.large$ ) which indicates firms with more than 500 employees. Furthermore, location is taken into account ( $region$ ) where we distinguish between "inside the Cluster", "Germany", "Europe" or "World". In order to control for persistence of network positions, we include indegree centrality of 2011 ( $Indegree.2011$ ). Table 3 shows descriptive statistics for the variables included in the regressions. Since we observed heteroskedasticity according to a Breush-Pagan test we use robust linear regressions for the analysis. Table A1 in the appendix reports the correlations between all independent variables.

As to the dependent variable, for 26 observations we recorded a decrease of their indegree implying a decline of their importance within the R&D network. The maximum loss of indegree is 2, means that the corresponding actor was named two times less as an important R&D partner in 2013 than in 2011. Contrariwise, for 42 actors the indegree centrality and therefore their importance in the network (slightly) increased. Surprisingly, we observe one actor that was mentioned eight times more in 2013



than during our first survey in 2011. For the remaining 74 actors, the majority, we observe no change of their indegree.

**Table 3: List of dependent and independent variables**

Variable	Explanation	Mean	Min	Max
d.deg	change of the (indegree) centrality of the actor from 2011 to 2013	0.296	-2	8
log.fin	total funding in second period (2013) (in log scale)	6.972	0	15.961
log.fin^2	squared term of total funding (in log scale)	94.223	0	254.762
num.proj	number of funded projects in second period	1.204	0	15
Indegree.2011	(indegree-) centrality of the actor in 2011	1.641	0	10
region	location of the actor (ordered: inside the Cluster = 1, Germany = 2, Europe = 3, World = 4)	1.620	1	4
public	public actor (yes = 1/no = 0)	0.373	0	1
actor.large	large enterprise (more than 500 employees) (yes/no)	0.331	0	1
cluster.actor	formal member of the leading edge cluster organisation in 2013	0.662	0	1
cluster	cluster dummy for each leading edge cluster			

These changes of relative network positions can either be caused by the LECC or appear as a result of strategic decisions with R&D ties regularly being established and dissolved within the innovation processes. To distinguish between these two different effects – policy induced and regular changes – we test a first set of models (model 1a/1b/1c) including only variables that are not directly related to LECC funding. The following independent variables are included: First, we expect the geographical location of an actor (region) or in other words the geographical distance to the cluster to be negatively related to the change in indegree; this is due to the observation that in high-tech research intraregional innovation linkages are typically of high importance (Koschatzky and Sternberg, 2000; Lublinski, 2003; Torre, 2008). Secondly, high-tech clusters are oriented towards more advanced innovation and therefore cooperation with universities and (public) research institutes should be considered relevant (Tödtling et al. 2009); hence the indegree centrality of a public actors should increase more than the one for a firm. Third, since large companies cooperate more often than small ones they also tend to change their partners more often and consequently changes of their indegree seem to be more likely. Finally and based on the preferential attachment argument, being more embedded can make an increase the indegree more likely due to a more exposed position or more experience with R&D cooperations (Barabasi and Albert, 1999; Wagner and Leydesdorff, 2005; Kim and Jo, 2010). Therefore the initial position inside the network should positively influence the change in centrality. At last we added cluster dummies to control for specific technology and innovation related factors inside the clusters.

Our estimation results show that for three specifications the initial indegree centrality has a significant impact on the observed changes of the indegree. The positive coefficient indicates that those actors which were considered important in 2011 increased their importance until 2013 – the networks as a whole tend to become more centralized with a few increasingly important actors at their respective core. During the short period 2011 to 2013, public actors become significantly less central whereas large firms tend to be able to increase their centrality compared to other private actors. In model 1c we include all non-policy variables<sup>1</sup>. In this overall model without policy variables only the significant effect for the indegree remains. For all three sets of our basic model we couldn't confirm – at least for the short run of 3 years – the importance of regional proximity for the loss or creation of linkages as expected according to Koschatzky and Sternberg (2000), Lublinski (2003) or Torre (2008). In a second model, we include cluster membership as a rather indirect measure for the policy impact of the LECC. Because of the high correlation we excluded the region in one specification (model 2a) while we include both in model 2b because of the low variance inflation factors. Interestingly, indegree in 2011 loses some significance while cluster membership has no influence on the change in importance of an actor for the network. Therefore we can't confirm for this model that sharing the commitment on the general strategy and vision of the cluster affects the creation of strategic relevant R&D cooperations. This result contradicts findings from our interviews in all five clusters where actors reported the cluster organisation and a corresponding membership as helpful for building up new R&D partnerships. It might be, that these new partnerships need more time than our observed period of nearly three years to become relevant for firm strategic aspects or to substitute established existing ones. Otherwise we are not able to exclude partially strategic answering during our interviews, while for the survey we are convinced that we received reliable answers, because we expected more partners from the founded projects mentioned as important R&D partner. To identify a potential direct impact of the LECC on the structure of the R&D network, we added the following direct policy measures to our model:  $\log.\text{fin}$ ,  $(\log.\text{fin})^2$  and  $\text{num.proj.}$ . In view of the high correlation between these variables we tested them separately in different models. We found a significant effect of the number of funded projects (model 3a – 3c) and of the total amount of received funding in its non-linear specification during the second period of the policy on the change of indegree centrality (model 4a – 4c). Looking at the influence of the financial volume of the subsidies delivers a significantly negative sign for the volume ( $\log.\text{fin}$ ) and a significantly positive sign for the quadratic term ( $(\log.\text{fin})^2$ ). This suggests a U-shaped relationship; however, a further extreme point

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<sup>1</sup> Because of their high correlation we calculated variance inflation factors which are in all cases lower than 4.

analysis of the impact of financial volume of subsidies on the change in the indegree centrality delivers more evidence for a monotonically increasing non-linear relationship.

Since one of the funded clusters reacts significantly different to the others (Solarvalley), we include interaction terms between the cluster dummy and the policy variables (model 3c and 4c). The number of granted projects as policy measure remains significant and also the interaction term for the Solarvalley turns out to be negative significant. This means that photovoltaic cluster actors, which are enrolled in more projects, are less likely to increase their importance within the R&D network. The reason for that finding is that especially large actors are more often part of different projects and therefore have a higher number of funded projects. In the special case of the Solarvalley some of these actors decided to shut down their activities in the field of photovoltaics after the LECC or even closed their business while one other large actor has been bought by Asian investors and therefore lost his attractiveness for R&D partnerships. When we test for interaction between the cluster dummy and financial volume, the significance of the quadratic term increases and for BioRN the change of the indegree centrality reacts significantly different compared to the other clusters. Independent from our model specifications the measures for a direct policy impact – the number of funded projects and the amount of funding – turned out to be positive significant for all cases while an indirect effect – through being a cluster actor – couldn't be identified. We can confirm that for our dataset the LECC as a cluster policy has a non-negligible positive impact on the creation of new strategic important R&D partnerships among the funded actors. Furthermore we can deny any selection bias towards any type of actor by the LECC since no other than our policy measures show any significance for the observed changes in the indegree centrality of actors. The results for all of our models are reported in table 4.

Furthermore we test our models 1c, 2b, 3b and 4a also for each cluster separately. The results are reported in table 5. For BioRN we cannot report any results because the regressions did not converge. Compared with our regressions for the whole sample, we observe different results for some clusters. While Hamburg Aviation, Cool Silicon and FOE are mostly in line with our overall results for the effect of their embeddedness into the network, Solarvalley shows the opposite effect. Nevertheless, for Hamburg Aviation none of our explanatory variables turns out to be significant on any level and therefore the development within this cluster differs quite recently from our assumptions. In contrast to that, Cool Silicon shows for 3 of our 4 tested models a high significance for the indegree.2011. In this cluster the initial position determines the change of importance of an actor while these strong influences cannot be observed for the other clusters. Furthermore, not all clusters react significantly positive to the measure for direct policy impact.

Table 4: Robust linear regression of the change of indegree centrality

	Model 1a	Model 1b	Model 1c	Model 2a	Model 2b	Model 3a	Model 3b	Model 3c	Model 4a	Model 4b	Model 4c
(Intercept)	0.1959	0.0926	0.1521	-0.1200	-0.1815	-0.2347	-0.2225	-0.1967	-0.0831	-0.1914	-0.2708
region	-0.0475	-0.0788	-0.0676		0.0250	0.0578	0.0589	0.0471	0.0426	0.0754	0.0420
public	-0.2768*		-0.1524	-0.1098	-0.1125	-0.0406	-0.0219	0.0243	-0.0526	-0.0442	-0.0181
actor.large		0.3076+	0.2294	0.2975	0.3116	0.2895	0.2991	0.0908+	0.2195	0.2498	0.2423
Indegree.2011	0.1293**	0.1040**	0.1123*	0.0989+	0.0998+		-0.0264	-0.1072	0.0283	0.0266	-0.0171
cluster.actor				0.2807	0.3003	0.1152	0.1042	0.3555+		0.1553	0.0918
no.proj						0.1943***	0.2123***	0.2961*			
Log.fin									-0.2315**	-0.2355***	-0.2387*
(log.fin)^2									0.0193***	0.0193***	0.0222***
BioRN	-0.1182	-0.0307	-0.0697	-0.0651	-0.0771	-0.1050	-0.1082	0.0349	-0.2430	-0.2606	0.1154
Cool Silicon	0.2269	0.2175	0.2017	0.1551	0.1539	0.2784	0.2860	0.2239	0.2139	0.1775	0.3755
FOE	-0.1809	-0.2094	-0.2152	-0.2448	-0.2496	-0.1978	-0.1972	-0.2521	-0.2709	-0.2833	-0.2016
Solarvalley	-0.3089	-0.3801	-0.3557	-0.4160	-0.4130	-0.4797+	-0.4978+	-0.0624	-0.4916+	-0.5182+	-0.1473
BioRN x no.proj								-0.2235			
Cool Silicon x no.proj								0.1250			
FOE x no.proj								0.0421			
Solarvalley x no.proj								-0.3517*			
BioRN x log.fin											-0.0701+
Cool Silicon x log.fin											-0.0298
FOE x log.fin											-0.0140
Solarvalley x log.fin											-0.0585
Observations	142	142	142	142	142	142	142	142	142	142	142
Degrees of freedom	134	134	133	133	132	132	131	127	131	130	126
Residual standard error	0.7267	0.6462	0.6419	0.6397	0.6433	0.655	0.673	0.6842	0.6875	0.6427	0.6536

Signif. Codes: + p&lt;0.1 ; \* p&lt;0.05 ; \*\* p&lt;0.01 ; \*\*\* p&lt;0.001

**Table 5: Robust linear regression of the change of indegree centrality per cluster**

	Hamburg Aviation				Cool Silicon			
	Model 1c	Model 2b	Model 3b	Model 4a	Model 1c	Model 2b	Model 3b	Model 4a
(Intercept)	0.6738	-0.4480	0.8711	0.5945	-0.3820	-0.4288	-0.1204	-0.0553
region	-0.1513	0.0304	-0.2281	-0.0835	-0.1833	-0.1716	-0.1776	-0.1445
public	-1.0989	-0.5014	-1.1740	-0.9222	0.3175	0.3254	0.4245	0.1205
actor.large	0.1053	0.8834	0.0400	-0.0118	0.724+	0.7388	0.8935*	0.4878
Indegree.2011	0.1680	0.0883	0.2295	0.0427	0.5644***	0.5578***	0.1332	0.3889**
cluster.actor		0.8928				0.0415		
no.proj			-0.0903				0.2886*	
log.fin				-0.3462				-0.6224**
(log.fin)^2				0.0279				0.0467**
Observations	31	31	31	31	49	49	49	49
Degrees of freedom	26	25	25	24	44	43	43	42
Residual standard error	0.9017	0.9117	1.001	0.9616	0.8	0.778	0.6655	0.6934
	FOE				Solarvalley			
	Model 1c	Model 2b	Model 3b	Model 4a	Model 1c	Model 2b	Model 3b	Model 4a
(Intercept)	-0.7530	-0.7013	-0.4239	-1.9409+	0.4724	0.7676	0.2424	0.3498
region	0.1882	0.1698	0.2750+	0.5776+	0.0807	-0.0598	0.2482	0.0883
public	0.0414	0.0549	-0.0128	-0.0514	-0.6129+	-0.4700	-0.6973+	-0.6197
actor.large	-0.3141	-0.3089	-0.3319	-0.6605	-0.4478	-0.3340	-0.5359	-0.3565
Indegree.2011	0.3766*	0.3814+	-0.3501*	0.3078	-0.2911**	-0.3187***	-0.3443*	-0.2539*
cluster.actor		-0.0590				-0.2460		
no.proj			0.6721***				0.0746	
log.fin				0.2108				0.1360
(log.fin)^2				-0.0075				-0.0095
Observations	24	24	24	24	18	18	18	18
Degrees of freedom	19	18	18	17	13	12	12	11
Residual standard error	0.7447	0.7243	0.4077	0.8563	0.3892	0.2124	0.4389	0.3519

**Signif. Codes: + p<0.1 ; \* p<0.05 ; \*\* p<0.01 ; \*\*\* p<0.001**

The results for the overall analysis with a significant direct and indirect policy impact do not hold if we reduce our level of analysis to the cluster level. However for two of the leading edge clusters we can confirm a direct policy impact on the network structure.

## **6 Summary**

Our results show that over time the LECC program was effective in initiating R&D cooperation between cluster actors and in intensifying existing partnerships. A substantial share of the newly formed linkages is among actors who did not receive direct funding for a joint R&D project, which indicates a mobilisation effect of the policy that goes beyond government sponsored collaboration. The vast majority of linkages which are influenced by the LECC are located in the cluster region. During the early phase of the policy we identify mainly a local policy impact with some actors even reporting a decline in international activities in favour of new local partnerships. Following this policy influence common to all clusters, we observe differential developments regarding clusters' spatial embeddedness during the later stage. Some clusters tend to increase their localisation, whereas others increase their connectivity to international partners. All five case study clusters are centred around one or more global players and/or an excellent research institute or university and we find an increase in network centralization caused by the policy induced linkages. We employ standard regression techniques to characterise actors that benefit most – in terms of increased centrality – from the policy. If we do not control for funding, it shows that actors who were already central in the previous period and large firms benefit most, whereas universities and public research institutes become less central within the R&D networks. If direct policy measures such as the number of funded projects and the total amount of funding are included, all other variables turn insignificant and a positive effect of funding occurs. Apparently, the policy induced cluster development beyond direct funding does not favour any specific type of actor. Analyses for each cluster separately, lead to heterogeneous and inconclusive results. Apparently, evaluations of cluster policies should not rely on aggregated statistics that ignore cluster specific impacts. We suspect that such differential impacts are especially prevalent if clusters are as diverse and heterogeneous as within the LECC.

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## Appendix

**Table A1: Correlation between independent variables**

	region	public	cluster.actor	Indegree.2011	actor.large	num.proj	log.fin	(log.fin)^2	Cluster
region	****	0.051	-0.662	-0.229	-0.002	-0.358	-0.504	-0.503	0.104
public	0.551	****	-0.052	0.134	-0.512	0.016	-0.134	-0.13	0.009
cluster.actor	<0.001	0.536	****	0.212	-0.119	0.423	0.667	0.653	0.119
Indegree.2011	0.006	0.112	0.011	****	0.136	0.708	0.331	0.384	-0.117
actor.large	0.98	<0.001	0.158	0.106	****	0.042	0.038	0.059	0.142
num.proj	<0.001	0.846	<0.001	<0.001	0.62	****	0.659	0.706	0.027
log.fin	<0.001	0.112	<0.001	<0.001	0.657	<0.001	****	0.99	0.043
log.fin^2	<0.001	0.124	<0.001	<0.001	0.483	<0.001	<0.001	****	0.045
cluster	0.217	0.916	0.157	0.167	0.091	0.751	0.609	0.594	****

upper diagonal part contains correlation coefficient estimates / lower diagonal part contains corresponding p-values