What is behind the structure of regional networks in the German biotechnology industry?

Strotebeck, Falk

Ruhr-University Bochum

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Falk Strotebeck
Faculty of Economics, Ruhr-University Bochum
Universitätsstr. 150
44801 Bochum
falk.strotebeck@rub.de

Abstract: By using methods of network analysis I uncover the underlying structure of cooperation-linkages within and between regions on firm level for the German biotechnology industry. I show that intraregional as well as interregional linkages expose a distinctive set of regions as the most important players in the German biotechnology. These regions cannot be located in one specific spatially delimited area but are distributed over wide distances. The description shows that regarding the biotechnology industry neither local clustering nor far-ranging cooperation on its own seems to be sufficient when thinking about the role of distance.

Keywords: network analysis, interregional cooperation, network structure, centrality

JEL classifications: L22; R11; O33

Introduction: Using network analysis to show and describe the cooperation network of the German biotechnology industry, the results show a high degree of intra-, as well as interregional linkages. This gives an insight in how distance matters when looking at a complex nationwide cooperation network, with a network description that is not bounded to a single picked out region like in many case studies. Looking at *intra*regional networks is important of course (and therefore it is done in this study, too) but the main task - thinking of key concepts like Granovetters' "weak ties" and Burts' "structural holes" - is to integrate all the intraregional networks into one complex network that does include the linkages within and *between* the local networks. Like Anne L. J. Ter Wal and Ron A. Boschma (2009) write about the prevalent look at networks: *"Cluster borders were conceived to enclose knowledge networks, and collective learning processes were tied to the place of the cluster. When applying network theory, some of these strong assumptions of the cluster literature may be seriously questioned."* By applying network analysis on a network without such narrow boundaries the cooperation network of the German biotechnology shows a distinctive set of regions with the greatest amount of intra- and interregional linkages. Furthermore the results indicate path dependent development regarding the biotechnological industry base, when contrasting the network structure and the historical support of the German biotechnology.

While the concept of Granovetters' *strength of weak ties* focuses more on the ties itself, considering weak ties as the main source for the transfer of new knowledge, Burt highlights the point that the *position* of actors in networks building the bridges among strong tie networks is important to look at. These are the actors closing the structural holes in the network (Scheidegger 2010, Burt 1999, Granovetter 1973). Burt stresses the brokerage position of actors, who build the bridges between otherwise unconnected networks. By analyzing the network structure and calculating centrality measures for the actors within the network I use these concepts of network theory to explain the structure of the German biotechnology industry network and to give some political implications especially when thinking about diffusion oriented innovation policy. A central point to add is that innovative knowledge, transferred via weak ties between brokers, has to be recognized by local actors and they need to have the ability to adopt and apply such knowledge. The ability to do so is described as absorptive capacity (Cohen, Levinthal 1990).[1]

[1] Also see Trott, Cordey-Hayes, Seaton (1995) for the related 4A Model.

Regarding the biotechnology sector, which is observed for the German case in the following, Gertler and Levitte (2005) described for the Canadian case the *"complex geography of global and local linkages"*. They highlight the importance of gathering external knowledge on a global level for otherwise locally oriented networks. In the following I am interested to discover such a structure in case of the German biotechnology.

Network Data Collection and Boundary Spanning

For the following network analysis information about cooperation between researching firms and with institutions from the field of biotechnology has been gathered from the biotechnology Year- and Address-Book 2005 of the BiocomAG. Unfortunately the kind of cooperation mentioned in the Year- and Address-Book is not specified. In a first step out of the given 1700 data sets a selection of the 575 firms of the biotechnology core area with their main focus on research and development has been chosen. Secondly in regard to the interdisciplinary structure of the biotechnology every named cooperation partner that was not already covered by the core set of the 575 players has been added. The number of players increased to 1628. Before analyzing this dataset, in a third step these players were classified by their location, using the municipal code of the German Bureau of Statistics. Aggregated by their municipal code the number of actors (from here on these are better called the number of regions; the firms and institutions are still called actors) decreased to 295 that has then been used for describing the region to region network.

Regarding the third step, not only the set of actors has been limited, but also the regional expanse of the network. Three different types of network demarcations are divided in the following: **I** The network on national level including transnational cooperation linkages. **II** The network on national level without transnational cooperation linkages. And at last the network-type **III** uses the not aggregated data on firm level without transnational cooperation.

It has been reduced by an all recursive degree reduction procedure to a number of 436 actors to make it more manageable.

Nomenclature

A network consists of *vertices* or *nodes* which in this example represent the regions or actors. The vertices are connected via *edges* (or linkages) which reflect the observable cooperation between the regions and accordingly the cooperation of actors located within the regions. Therefore regions can be connected by one or more edges. If more than one linkage is observable, the connections are counted as *multiple lines* in the region to region network. Multiple lines are crucial to extract the core network using the m-slice-procedure. The m-slice-procedure is used to reduce the network to a *core network*, a network that only contains edges with a specific intensity defined by the chosen rate of *m* and captured by the multiple lines. Because regions often contain more than one actor of the biotechnology industry, it is possible that cooperation within a region can be observed. In this case two or more actors are cooperating, while being located within the same municipality. These connections display intraregional cooperation and are called *loops* in the following. It is the aggregated form of what can be observed in the actor to actor network within one region.

The regions contain the actors of the biotechnology industry. Not every actor and therefore even not every region is connected to the network. What is always meant here by *the network* is the biggest connected part of a network, known as the *main component*. In our example at an average about ten percent of the regions are not part of the main component. Some regions are not connected to any other region at all. Some other regions are connected but only build a component of two or three connected vertices. Some of the measures that reflect the importance of network positions cannot be calculated in unconnected networks. This is the reason why always the biggest component of the networks is used for the analysis.

The mainly used measures to illustrate the role of the positions of regions within the network-structure are based on three different forms of centrality. These are degree-, closeness- and betweenness-centrality. Sure, centrality might be considered a common term in general. But different kinds of questions about potential centrality in networks require measures that focus on the interested aspects which are asked for. For example one might ask: (1) Are regions in most central positions if they have lots of direct connections to other regions? (2) Is a region in a central position when information has to pass through it to get to its destination? (3) Is a region in a most central position, if it is on the shortest paths between the other remaining regions. All of these questions can be affirmed without doubt, but all of them ask about different kinds of *centrality*. For each kind there is another measure in network analysis that can and will be calculated and interpreted.[2]

Observing intra- and interregional cooperation

Hereafter a few descriptive statistics of the German biotechnology network on regional level are shown, before intra- and interregional cooperation are uncovered and the most important regions are identified using centrality based measures.

	Main Component			
Network-type	Vertices	Edges	Loops	Multiple lines
Type I	295	2799	926	1550
Type II	244	2153	916	1238

Table 1 Descriptive statistics

[2] See appendix A for details.

Right at a first glance two things are visible. For one thing, more than fifty percent of identified connections are multiple connections, a first indicator for the importance of specific cooperation linkages. And for another thing, nearly a third of all linkages are identified as loops and hence they present *intra*regional cooperation. Furthermore about 30 percent of all linkages in the type I network are transnational. The main countries for transnational cooperation are the USA, Great Britain and Switzerland.

What has to be identified are regions with a high number of relevant industry actors, great network strength and cooperative linkages to other local networks for a wider knowledge base and connections to more isolated actors to span the diffusion channels to the periphery.

The following table (using network-type III) shows the regional distribution of linkages per actor of a given region. The idea behind this is that every actor within the network has limited resources regarding the number of cooperation linkages and therefore affecting the choice of cooperation partners. Not going deeper into the decision process, one interesting fact looking at the cooperation linkages is displayed by the fraction of cooperation linkages per actor with actors within the region or with external actors.

		01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16
01	Schleswig Holstein	**3.20**	0.32	0.04	0.20	0.21	0.10	0.00	0.03	0.08	0.00	0.19	0.00	0.33	0.00	0.00	0.13
02	Hamburg	0.60	**1.68**	0.25	0.40	0.31	0.17	0.11	0.16	0.38	0.20	0.15	0.07	0.00	0.18	0.13	0.13
03	Lower Saxony	0.10	0.32	**2.88**	0.60	0.19	0.21	0.00	0.33	0.28	0.00	0.11	0.53	0.50	0.12	0.13	0.13
04	Bremen	0.10	0.11	0.13	**2.80**	0.07	0.14	0.00	0.01	0.07	0.00	0.04	0.07	0.00	0.06	0.00	0.25
05	North Rhine-Westphalia	1.60	1.21	0.58	1.00	**3.21**	1.10	1.11	0.56	0.63	0.40	0.74	0.87	1.00	0.71	0.60	0.50
06	Hesse	0.30	0.26	0.25	0.80	0.43	**1.86**	0.33	0.27	0.41	0.20	0.49	0.20	0.17	0.06	0.27	0.38
07	Rhineland-Palatinate	0.00	0.05	0.00	0.00	0.13	0.10	**1.56**	0.10	0.17	0.20	0.11	0.20	0.00	0.12	0.13	0.00
08	Baden-Wuerttemberg	0.20	0.58	0.96	0.20	0.52	0.66	0.78	**3.49**	0.84	0.80	0.79	0.53	0.83	0.41	0.27	*1.75*
09	Bavaria	0.60	1.53	0.88	1.00	0.64	1.07	1.44	0.91	**3.13**	0.20	0.85	0.80	0.00	0.35	0.67	0.75
10	Saarland	0.00	0.05	0.00	0.00	0.03	0.03	0.11	0.06	0.01	**2.40**	0.02	0.00	0.33	0.06	0.13	0.00
11	Berlin	1.00	0.42	0.25	0.40	0.52	0.90	0.67	0.60	0.59	0.20	**3.32**	*2.33*	0.17	0.53	0.53	0.38
12	Brandenburg	0.00	0.05	0.33	0.20	0.17	0.10	0.33	0.11	0.16	0.00	0.66	**1.87**	1.00	0.18	0.13	0.13
13	Mecklenburg-Western Pommerania	0.20	0.00	0.13	0.00	0.08	0.03	0.00	0.07	0.00	0.40	0.02	0.40	**5.33**	0.06	0.07	0.00
14	Saxony	0.00	0.16	0.08	0.20	0.16	0.03	0.22	0.10	0.08	0.20	0.17	0.20	0.17	**2.53**	0.40	0.75
15	Saxony-Anhalt	0.00	0.11	0.08	0.00	0.12	0.14	0.22	0.06	0.13	0.40	0.15	0.13	0.17	0.35	**2.27**	0.50
16	Thuringia	0.10	0.05	0.04	0.40	0.05	0.10	0.00	0.20	0.08	0.00	0.06	0.07	0.00	0.35	0.27	**1.63**

Table 2 Regional distribution of linkages

In table 3 we can see column by column the distribution of the average number of cooperation linkages as fractions with the federal states. Row by row the table displays for each federal state (1 to 16) what fraction of linkages per actor is distributed by the other federal states.[3] On average the regional actors in the region of Schleswig Holstein distribute 3.2 of their linkages per actor to partners within the federal state. One cooperation linkage per actor is between Berlin and Schleswig Holstein and 1.6 linkages of regional actors of Schleswig Holstein are with North Rhine-Westphalia. On the other side, because of the higher number of actors in North Rhine-Westphalia the relative importance of linkages measured as the amount of linkages per actor with actors from Schleswig Holstein declines. Actors of North Rhine-Westphalia distribute their potential amount of cooperation linkages only to 3 percent to Schleswig Holstein. Much more relevant for North Rhine-Westphalia are the connections to Bavaria (0.65), Baden-Wuerttemberg (0.52) and especially to local actors within the federal state (3.21).

[3] For a graph, see appendix B.

General evidence of the importance of local cooperation can be concluded from the values on the diagonal line in the table. In nearly all of these cells the highest count of linkages per actor is shown, even though there is a remarkable difference between the regions. Especially interesting are the distributions of linkages per actor in Rhineland-Palatinate, Brandenburg, Thuringia on the one hand and Baden-Wuerttemberg, Bavaria, North Rhine-Westphalia, Berlin on the other hand.

But first things first, Rhineland-Palatinate seems to reach out its' cooperation linkages to all the most important regions of the biotechnology in Germany (as I say, these are especially in terms of network positioning Bavaria, Baden-Wuerttemberg, North Rhine-Westphalia and Berlin). 23 percent of the cooperation linkages per actor are local (1.56) and another 60 percent are distributed between actors of Bavaria, North Rhine-Westphalia, Berlin and Baden-Wuerttemberg. Thuringian actors distribute their linkages mainly on Baden-Wuerttembergian (24 percent) and local actors (22 percent). But they also distribute about 10 percent of their linkages to the geographical neighbors Bavaria and Saxony respectively. Brandenburg, framing Berlin, distributes its' linkages mostly to Berlin (2.33 linkages per actor; about 28 percent) and locally (1.87 linkages per actor; 23 percent).

Looking at the four regions of Bavaria, Berlin, North Rhine-Westphalia and Baden-Wuerttemberg the results show a very high proportion of local cooperation linkages per actor for each of the regions. Additionally the most important external regions for cooperation linkages are the remaining three regions out of the four mentioned ones respectively.

Looking at the network-type II (cooperation within national boundaries) over 40 percent of all edges are identified as loops. This means that over 40 percent of the linkages exist between actors within a German municipality. This portion does not only differ between the federal states but as well between the municipalities within the federal states. So, concerning the unequal distribution of local cooperation when looking at federal states, the number of loops varies greatly between municipalities. Therefore the next figure shows how many loops can be assigned to individual regions in Bavaria, Baden-Wuerttemberg and North Rhine-Westphalia.

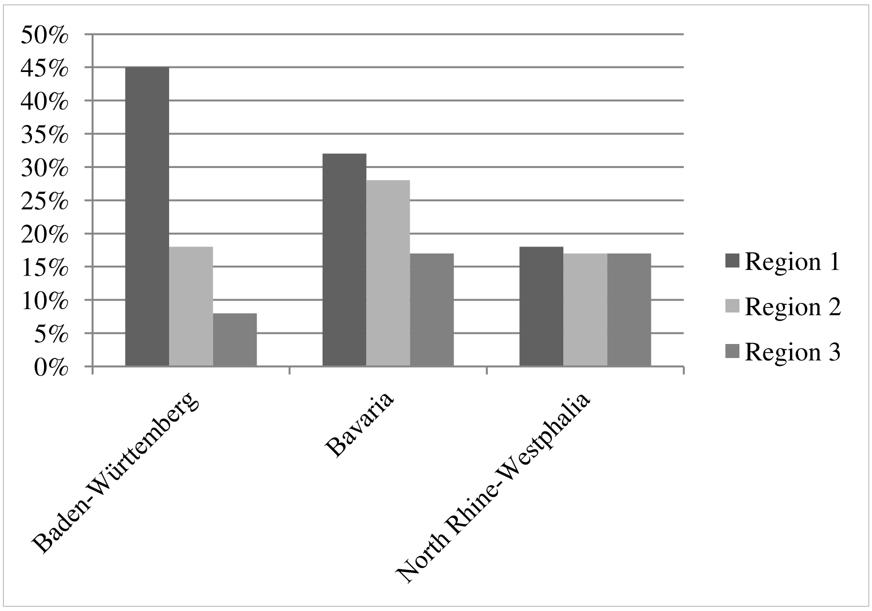

Figure 1 Intraregional cooperation

On the x-coordinate some selected regions (for each federal state the three municipalities with the highest percentage of local linkages) are shown. Especially in Baden-Wuerttemberg and Bavaria the percentage of local contacts is more unequally distributed than in North Rhine-Westphalia. Using the type V network structure 70 percent of the counted loops can be assigned to three municipalities only. Heidelberg possesses most of them with a percentage of 45 of all counted loops, followed by Freiburg (18 percent) and Tuebingen (8 percent). In Bavaria the region of Planegg is ahead with 32 percent, followed by Munich (28 percent) and Regensburg (13 percent). A more or less equal distribution among the leading regions can be shown for North Rhine-Westphalia. Muenster is ahead with 18 percent, followed by Juelich and Cologne (17 percent each).

This result is driven by two factors. Most often the central localities contain more companies and institutions than other regions. This shows the importance of a municipality regarding the companies' decisions to locate or stay in the region, but at the same time, the sheer number of loops is not enough to evaluate the local network strength. One possible solution is to calculate the network density of the networks within the municipalities. But density again is heavily influenced by the number of actors and is therefore very low, if the number of actors is high (De Nooy, Mrvar, Batagelj 2005). But structural cohesion can be calculated by using the average degree of vertices (De Nooy, Mrvar, Batagelj 2005). In this case it's the average degree of actors within a municipality, when only allowing cooperation with local partners. What we can see, when looking at the average degrees, the inequality of the distribution shrinks. Especially in North Rhine-Westphalia the municipality of Juelich shows a high structural cohesion (average degree of 2.86) and gains the lead, followed by Muenster (1.25) and Cologne (0.75). The ranking of the municipalities is still the same in Baden-Wuerttemberg with Heidelberg on top with an average degree of 2.1, followed by Freiburg (1.27) and Tuebingen (1.25). In Bavaria Regensburg has the highest average degree of 1.67, followed by Munich (0.78) and Planegg (0.73). In Bavaria, because of high interregional cooperation between Planegg and Munich and their close distance, it does make sense to sum up the two regional clusters. If done so, the average degree raises up to 1.65.

The strength of the connections *between* local networks, especially across state boundaries, has partly been seen in table 3 and can be captured on municipality level by using a so called the m-slice-procedure. Figure 2 shows the biotechnology core-network after using the procedure on municipality level with a chosen value of *m* of six. This means, every shown linkage between two regions is counted at least six times. Thicker lines indicate higher cooperation intensity, measured by counting the number of linkages (loops are not integrated). The eight-digit numbers are the municipality codes of the regions. This way the interregional cooperation (especially between municipalities in Germany, but countries for transnational linkages are also integrated) can be measured.

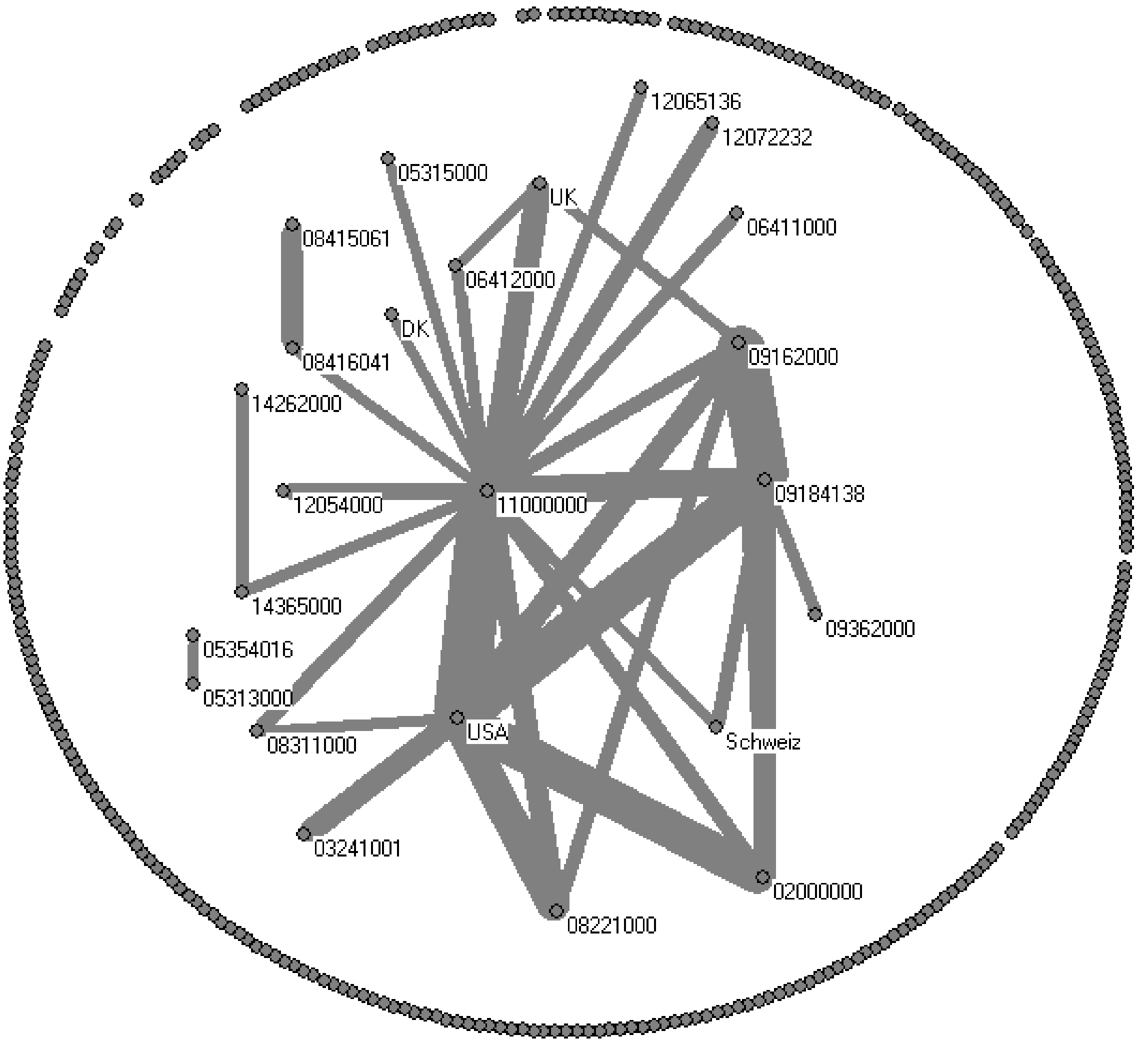

Figure 2 Network core on municipality level

The network is reduced to its core, meaning a network that is characterized by a specific strength of cooperation linkages. Taking a look at the regions with intense intraregional cooperation networks (as presented before, these are for example Planegg[4] [09184138], Heidelberg [08221000] and Muenster [05515000]) one can see a difference in their national and transnational involvement and therefore in their position regarding the core structure of the German biotechnology network. Heidelberg and Tuebingen [08416041] have many linkages with Munich [09162000] and Berlin [11000000] on a national level and with the USA and Great Britain on an international level. Munich and Planegg show intense

[4] The municipal code is named in squared brackets, when a region is mentioned for the first time in this section.

cooperation with each other and with Berlin, Hamburg [02000000], Heidelberg and Regensburg [09362000] on a national level and with the USA, Switzerland and Great Britain on an international level. Regions from North Rhine-Westphalia (like Muenster) merely show a low involvement in national and international cooperation. We can see that only Cologne [05315000] shows intense cooperation with Berlin. No other region from North Rhine-Westphalia is connected to the core. Muenster, as the region with the highest intraregional cooperation in terms of counted loops is not connected to the core and neither is Juelich [05358024] as the municipality with the highest structural cohesion in North Rhine-Westphalia. One can often see the stronger involvement of regions that can be identified as central by calculating centrality measures in the following.

Centrality of regions

The centrality of regions/actors within the biotechnology network is measured in three ways: (1) Degree-centrality, when especially looking out for independent actors in the network. (2) Betweenness-centrality, used to identify actors in gatekeeper-positions. (3) Closeness-centrality, when searching for actors with positions which offer high efficiency regarding gathering and spreading information. Independent actors show a great number of direct linkages and therefore are able to get information at first hand. Gatekeepers are in positions in which they are able to control knowledge flows. Central actors, measured by closeness, have on average the shortest path to all other actors. Therefore these actors may spread information more efficiently than others (Freeman 1978/79).

The most central regions (concerning all centrality measures while using the network-type II) are Berlin and Hamburg, followed by regions like Munich and Planegg (both Bavarian regions) and Heidelberg, Tuebingen and Freiburg (all three regions from Baden-Wuerttemberg). Concerning the formerly mentioned regions of the three federal states

Bavaria, Baden-Wuerttemberg and North Rhine-Westphalia (see figure 1), the following ranks are achieved by the regions (*without counting loops and multiple lines*).

	Degree-centrality		Closeness-centrality		Betweenness-centrality	
	Rank	Value	Rank	Value	Rank	Value
Heidelberg	5	0.173	7	0.467	7	0.066
Freiburg	8	0.132	8	0.466	4	0.092
Tuebingen	6	0.144	5	0.476	5	0.083
Planegg	3	0.189	4	0.480	3	0.093
Munich	4	0.177	3	0.484	6	0.079
Regensburg	30	0.058	17	0.430	44	0.010
Muenster	13	0.103	16	0.434	8	0.056
Juelich	21	0.070	47	0.396	34	0.017
Cologne	9	0.119	12	0.447	12	0.041

Table 3 Centrality

The results show the centrality of regions concerning their position in the network structure. Because loops and multiple lines have been left out of the calculation (for mathematical reasons) the number of intraregional linkages and intense cooperation between (for example only two) regions play no direct role in identifying the structural position. It maybe plays an indirect role. For instance you could argue that a region with a strongly connected local network and a big number of local companies is recognized widely in the national network and is therefore a primarily chosen partner of other regions in many times. This in case would lead to a high degree-centrality. Because the data about the cooperation linkages on hand only allows a static look at the network, causality of this argument cannot be verified in this study. Nevertheless it can be an explanation for an indirect effect. However the results show a good accordance with what can be seen in figure 1 and figure 2.

The regions with intense intraregional as well as interregional cooperation also function as *hubs* in the network structure, as can be seen looking at closeness- and degree-centrality in particular. Hubs in networks have many more linkages than other nodes. Because of this they have great influence on connectivity and information-flow in complex networks.

Therefore hubs are predestined to be observed and supported by policy makers. Innovative hubs can spread information efficiently as well as they have the status to be accepted as a precursor. Empirical studies show that the path distance between two players heavily depend on the existence of hubs. The path to a hub is generally short and the hub has a wide range of different contacts so it can often be used as a shortcut to the destination (Barabàsi 2003). But without identifying the right actors as hubs, reaching the destination might take a long time and means to walk along a long path in the network (Barabàsi 2003).

In addition to the function as an efficient information allocator, the position of hubs as bridges between clusters leads to their importance for avoiding structural and technological lock-in effects (Burt 1999). Separate clusters in a network might get deadlocked in their procedures and routines. As long as external sources are not integrated, the actors within a cluster are dependent on their internal knowledge base. This may lead to a development that departs the players from the rest. Hubs have the status to function as opinion leaders and they have the position to reconnect clusters that are at risk to get locked-in. Technological lock-in effects hereafter mean the path dependent diffusion of an innovation. Changing between an adopted innovation and a so far rejected competing innovation induces costs. A widespread innovation therefore might not get caught up by an even more beneficial innovation. Hubs offer opportunities to intervene before this occurs because of their status and position. When in gatekeeper-position, hubs can slow down or stop the diffusion of the unfavorable innovation. With their status as opinion leaders they also have the opportunity to convince players of advantageous innovations and their high integration in the network can lead to rapid diffusion. Therefore identifying positions is crucial to utilize their benefits (Grabher 1993, Arthur 1989, Maggioni 2002, Boschma 2005).[5]

[5] An example can be found in David (1985). Also see Windrum (1999).

Sometimes there are a lot of actors located in the same municipalities, which is especially the case in Berlin and Hamburg. This gives us quite a good reason for their high relevance, even when talking about positioning. Therefore I take a look at the core network on actor level, to see if there is more than a size effect reasonable for the position within the network. Additional information can be gathered by looking at the average degrees of the regions. The regions of Berlin and Hamburg show completely different network strength, with an average degree of 0.63 in Hamburg but a high degree of 3.05 in Berlin. This result is also reflected by the centrality measures. The most central actor, regarding all three centrality measures, is the Charité in Berlin. The value for closeness is 0.35, the value for betweenness 0.2 and the normalized degree has a value of 0.08. The second most central actor regarding betweenness and normalized degree is the dkfz[6] in Heidelberg. But the values of these centrality measures are not even half as big with values of 0.06 (betweenness) and 0.04 (normalized degree). All in all, 19 percent of the actors located in Berlin are in the upper tenth regarding the betweenness, 21 percent regarding the normalized degree and 32 percent regarding the closeness. In contrast to this only 5 percent of actors in Hamburg are part of the upper tenth regarding all three centrality measures.

Looking at the history of politically initialized support for the biotechnology industry, there is a great overlap between the mainly supported regions and the central regions that has been identified in the network. Because I don’t have data to analyze the dynamic of the network over time I just can hypothesize causality between the support and the location of companies and the relevance of regions in the national network structure. But with recourse to models of network evolution, the nowadays observable network structure and the history of support go well together.

[6] German Cancer Research Center (Deutsches Krebsforschungszentrum)

In the mid of the eighties four gene centers has been supported by the German government. As a result of this support, private investment in the regions has been encouraged. The regions were Heidelberg, Munich, Cologne and Berlin. Regarding the support in the starting phase of the initialized race to catch up with the USA and Great Britain the path dependent development of the regions is unsurprising (Biotechnologie.de 2008). Further support was given to the regions of Heidelberg, Munich and Cologne, as these regions been declared winners of the BioRegio Competition in 1996 (Dohse 2005). Regarding the network structure and the relevance of individual regions the two stories fit together well.

As an exploratory concept the fitter-get-richer model (Bianconi, Barabàsi 2001) as an enhanced version of the preferential attachment model (Barabàsi, Albert 1999) can be consulted. The preferential attachment model assumes that more nodes get attached to the existing network in every period. The probability to attach to a specified node is influenced by the number of linkages the specified node already has. Therefore the older nodes in the network get more and more linkages. But whereas the preferential attachment model lacks in the explanatory power to allow younger nodes to catch up or get ahead of older nodes the fitter-get-richer model introduces an additional fitness parameter to allow for this to happen. Nodes in a network with a high fitness parameter increase the possibility to be chosen as a partner. Albert-Làszlò Barabàsi (2003) describes the fitness parameter as *"a quantitative measure of a node's ability to stay in front of the competition."*

Regarding the German biotechnology network the older nodes (the regions with the gene centers like Heidelberg etc.) seem to be in advantageous positions in two ways. (1) They got supported in an early stage of the catch up process. (2) They won the BioRegio Competition, what might be interpreted as an indicator for a higher fitness parameter. Both arguments would indicate a high attractiveness of these regions for new actors to get attached to.

Conclusion: The application of network analysis to observe intra- and interregional cooperation within the German Biotechnology Network delivers details concerning the linchpins within the network structure. It shows that the structure of a complex network is not random or something that can be taken for granted, but features specific characteristics that can be identified.

It is shown that a core network regarding the German biotechnology especially includes the regions of Berlin, Munich, Planegg and Heidelberg. These regions are characterized by structural cohesion and central positions within the network structure. The cooperation linkages between regions over wide distances (nearly crossing the whole nation while disregarding transnational cooperation linkages at this point) mark channels of knowledge flow, which can be seen as available bridges between local networks. In conjunction with the theory of the strength of weak ties, the local knowledge bases are increased by such cooperation.

In this case supporting the core regions does not mean to neglect peripheral regions at the same time. In many cases the more peripheral regions show connections to the most important regions. Nevertheless, especially the 10 percent of the regions that are not yet connected to the biotechnology network have to catch up, if they want to participate of the networks' advantages. Connected regions may benefit, even when support is focused on the core regions, because knowledge diffuses within a network, especially when accelerating diffusion is a central part of innovation policy strategies (Welsch 2005). Especially the central actors in a network have the possibilities to spread innovations faster. But a crucial factor, which has to be paid attention to, is the absorptive capacity of actors and/or regions. Without the ability to recognize, adopt and apply new innovations or knowledge, potential advantages persist unused.

Supporting regional networks may be considered as a first step, but regarding the *German* biotechnology at large, such strategies will encounter difficulties. The aim to tap the full potential of networking means to recognize the structure of a network beyond narrow or administratively given spatial boundaries. Three essential parts of a network supporting strategy are: (1) Central actors can act as regional hubs, gathering and spreading information in homophile clusters. (2) On national and transnational level, these central actors can act as brokers between heterophile clusters, to keep the pool of information *fresh*.[7] (3) Absorptive capacity of (especially) peripheral regions has to be influenced, for example by the use of academia support or supporting research and development cooperation or staff exchange programs.

What remain to be coordinated are the expectations of brokers and recipients. Neither should brokers rely on recipients to recall information, especially because they might sometimes don't know about potential new one. Nor should recipients think of an obligation to deliver on the part of the broker, who customize and pass on information on their needs without further ado (Berger 2005, 44).

[7] See regarding homophily and heterophily Rogers (2003) and Tarde (1903).

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Appendix A – Centrality Measures

Degree-centrality: This measure counts the number of direct linkages between a vertex p_k and a vertex p_i. The term $a(p_i, p_k) = 1$ if p_i and p_k are directly connected. Otherwise the result of the term is zero. Therefore the degree-centrality C_D for vertex p_k is:

$$C_D(p_k) = \sum_{i=1}^{n} a(p_i, p_k) \tag{1}$$

A problem arises. Compare a closeness-centrality of 25 in a network of 300 nodes with a 25 in a network of 30 nodes (Scott 1994). It's clear that in a network with more participants the centrality may systematically be higher in absolute terms because of the many more possible contacts. Reasonable for a comparison between different sized networks therefore is the *relative* closeness-centrality. The number of direct linkages must be divided by the maximum of possible direct contacts of p_k. The result (where *n* describes the number of nodes in the network) then is (Freeman 1978/79, 220-221, Scott 1994, 88):

$$C_D^{'}(p_k) = \frac{\sum_{i=1}^{n} a(p_i, p_k)}{n-1} \tag{2}$$

A high value of centrality may be interpreted as high communication activity and certify a high degree of independency (Freeman 1978/79).

Closeness-centrality: The centrality based on closeness counts the geodesic distances $d(p_{i,} p_k)$ between a vertex p_k and all other vertices of the network. The number of network vertices (minus 1) divided by the sum of geodesic distances shows the closeness-centrality.

$$C_C^{'}(p_k) = \frac{n-1}{\sum_{i=1}^{n} d(p_i, p_k)} \tag{3}$$

It ranges from zero to one, where a value closer to one displays higher centrality. Nodes with a high closeness-centrality can spread information efficiently, because of their short paths to all other nodes (Freeman 1978/79, Trappmann, Humell, Sodeur 2005). Compared to the degree-centrality the integrated information is extended by indirect contacts.

Betweenness-centrality: This kind of centrality is based on the probability that a vertex p_k lies on the shortest path between other vertices (for example p_i and p_j). Depending on how many possible shortest paths are between the other nodes, the paths on which p_k has to be passed gets weighted. The term for betweenness (with $b_{ij}(p_k)$ as the probability that p_k is on the shortest paths between p_i and p_j) is (Jansen 2006):

$$C_B(p_k) = \sum_{i<}^{n} \sum_{j}^{n} b_{ij}(p_k) \tag{4}$$

The result is not comparable between different sized networks. To allow for such a comparison the result must be set in relation to the highest possible value of the node. Freeman (1978/79) has shown that this maximum value is reached for a central node in star-like-structured network.[8] The value is presentable by the fraction: $\frac{n^2 - 3n + 2}{2}$. The rearranged term for a betweenness-centrality measure that is comparable between different sized networks is:

$$C'_B(p_k) = \frac{2\sum_{i<}^{n} \sum_{j}^{n} b_{ij}(p_k)}{n^2 - 3n + 2} \tag{5}$$

[8] In a star-like-structured network a node (A) has direct contacts to all other nodes (B, …, N). The other nodes (B, …, N) are not connected with each other, but only have linkages to the one central vertex (A).

Nodes with a high degree of betweenness-centrality are in gatekeeper-positions. They have the opportunity to intercept and/or control information-flow (Freeman 1978/79).

Appendix B – Graph containing information of distribution of linkages

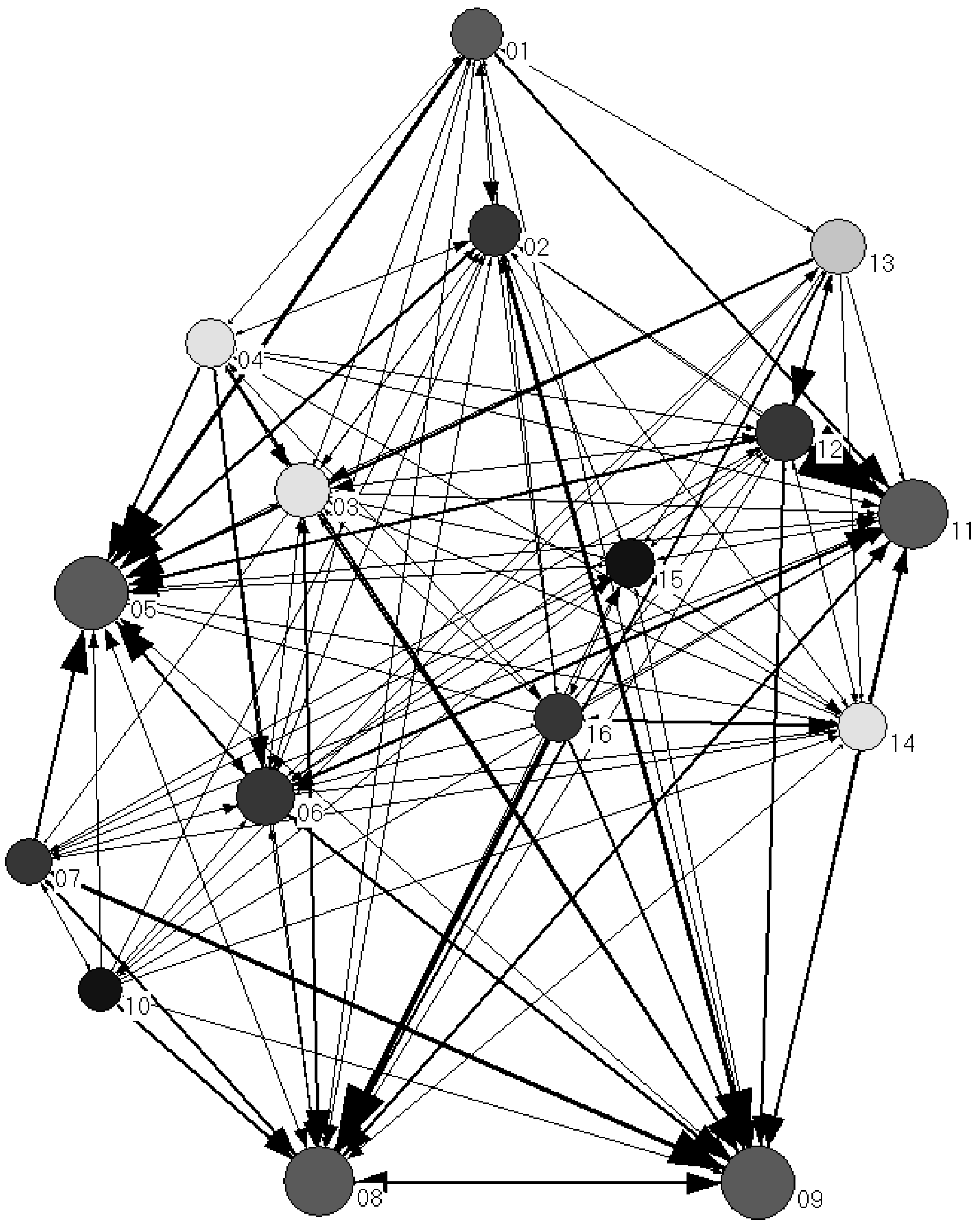

Figure 3 Cooperation linkages

The graph shows the distribution of linkages presented in table 3 in another form. The grey-scaling of the dots reflects classes of intraregional cooperation strength. The two-digit numbers present the federal state code. We see for example that Schleswig Holstein (01), North Rhine-Westphalia (05), Baden-Wuerttemberg (08), Bavaria (09) and Berlin (11) are in one class. Looking at table 3, these are regions in which the actors distribute between three to four edges per node to local actors.