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Public Research in Regional Networks of Innovators: A Comparative Study of Four East-German Regions

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Abstract

Universities and public research organizations are said to be an integrative and essential element of a functioning innovation system as they play a vital role not only in the generation of new technological knowledge, but also in its diffusion. We analyse four East German local networks of innovators which differ in structure and innovative performance and investigate the characteristic role of public research within these local systems by applying methods of social network analysis. Our results show that universities and non-university institutions of public research are key actors in all regional networks of innovators both in terms of patent output and in terms of centrality of their position in the networks. Further we find the 'thicker' networks to have more central public research organizations. Higher centrality of public research compared to private actors may be due to the fact that universities are explicitly designed to give away their knowledge and that they increasingly face the need to raise external funds.

Keywords: Innovator Networks; Public research; R&D Cooperation; Mobility

JEL Classification: O31; Z13; R11

1 Introduction

We analyse local networks of patent innovators in four East German regions. Besides interesting results regarding structural differences between these regions, we can demonstrate the constitutive role of public research within these local networks in our study. Further, an attempt is made to link network characteristics and innovative performance of the regions.

Adopting the system of innovation approach as a conceptual framework (Edquist, 1997), we view innovative activity as a collective process characterized by a transfer of knowledge between networked actors. Knowledge, especially if it is partly tacit, can only be transferred via personal relationships. Geographical proximity facilitates these

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face-to-face contacts. Therefore, regions are a reasonable level of analysis (Cooke, 1998). Innovative activity can then be modelled as a social network "boxed" in a region.

Following Cantner and Graf (2006), we use relational patent data to build the networks. More precisely, we link patent innovators both by joint application and the mobility of inventors switching between them, and we interpret these links as knowledge flows. According to a distinction put forth by Breschi and Lissoni (2004), we analyse relationships based on co-patenting as well as on co-invention. However, patents are also used in the traditional way as an indicator of innovative output both to weight the network actors and to assess the innovative performance of the regions as a whole.

Among the network actors we are explicitly interested in public research organizations, mainly universities but also non-university publicly funded research institutes. One function public research is usually expected to serve within local innovation systems is to provide innovative input to the region: Generating and accumulating basic scientific knowledge, collecting knowledge external to the region and integrating it into the regional knowledge stock, and educating a highly skilled workforce to keep the region's private economy capable of performing high-level industrial R&D (Fritsch and Schwirten, 1999).

However, university professors and even more so researchers at those public research organizations devoted to applied research have always been involved in direct cooperation with industry and have patented the results. Besides the creation of academic spin-offs, patenting is an important element of the emerging new entrepreneurial role of public research (Etzkowitz, 2003), encouraged by policy programs trying to enhance the impact of public research outcomes on national economic growth (Mowery and Sampat, 2005).

Despite these recent developments, patents are one of the few accessible sources reporting standardized larger scale information about the knowledge flows between public research and private economy. As we will show in our analyses, public research patenting can in fact play a significant role in local innovation systems. Moreover public research organization shape these networks and, since they still have different motives and incentives than private actors, may well serve specific and presumably essential functions within the process of collective invention.

The paper proceeds as follows: Section 2 introduces the four sample regions and compares their innovative performance using patent output data. Section 3 exposes the methodological approach, presents visualization of the regional networks of innovators and analyses the network's structure and characteristics. Section 4 elaborates the distinctive role of public research organizations as network actors. Section 5 concludes.

2 The Regions: Rostock, Halle, Jena, and Dresden

2.1 Selection of regions

In our explorative study, we restrict the analysis to four East German regions: Dresden, Jena, Halle, and Rostock.[1] With the exception of Rostock all regions are of similar size with roughly one million inhabitants (table 1). Each region exhibits a research university and a number of public research organizations such as institutes of the Fraunhofer society, the Leibniz society, and the Max-Planck society. All regions have considerable tradition in manufacturing industries: electronics and mechanical engineering in Dresden, optics and precision mechanics in Jena, chemicals in Halle, shipbuilding and mechanical engineering in Rostock. Two different types of regions arise ex ante as Jena and Dresden on the one hand are often labelled as East-German boom regions having successfully managed economic transformation after German reunification, whereas Rostock and Halle on the other hand are said to lag behind. We will confirm this prejudice by reporting pronounced regional differences in innovative performance and attempt to explain these differences by the role of public research in the respective innovation systems.

The geographical boundaries of the regions are defined as German planning regions ("Raumordnungsregionen"). Designed to represent socio-economic entities, they normally comprise several districts ("Kreise", i.e., German NUTS3 level units), namely a core city and its surrounding area. We consider planning regions to be more suitable than districts, firstly because local innovation systems, though concentrated in the center, may well include some R&D capacities located somewhat beyond the boundaries of the core city. The second reason is methodological: Because patents are assigned to regions in accordance with the inventors' residence, this larger regional unit allows to account for commuting inventors who work in the city but live in the surroundings.

2.2 Innovative potential and patent output

As a starting point and to provide a reference framework for the following investigation of the networks of innovators we present basic comparative data of the regions and their economic potential for patenting as well as of regional patent efficiency (table 1).

The regional differences are small in respect of the share of private sector employees in total population (25% up to 28%) as well as for the average firm size (10.0 up to 11.5 employees per firm). But we observe striking differences when it comes to the share of private sector natural scientists and engineers. Halle displays only about 75% of the Dresden value, Rostock and Jena only about 62%. In absolute figures the distance between Dresden and all other regions is impressive.

[1] A comprehensive investigation of the role of public research in local innovator networks should include all 97 planning regions or at least those which meet the requirement of local public research organizations. Unfortunately, we have not been able to do the necessary data processing for all regions yet.

Table 1: Regional innovative potential and patent output (mean yearly values)

	Dresden	Jena	Halle	Rostock
Population (1994 - 2000)	1,035,486	794,471	893,614	438,643
Private sector (1994 - 2000[a])				
Firms[b]	26,976	20,059	19,775	10,923
Employees	291,791	201,167	226,668	111,401
Natural scientists and engineers[c]	12,052	5,170	6,990	2,901
	(4.13%)	(2.57%)	(3.08%)	(2.60%)
Universities[d] (1994 - 2000)				
Total research and teaching staff	3,775	2,633	2,642	1,741
in natural sciences and engineering[e]	2,172	918	1,098	656
	(58%)	(35%)	(42%)	(38%)
Professors	704	452	425	289
in natural sciences and engineering	454	193	185	142
	(64%)	(43%)	(44%)	(49%)
Patents (1995 - 2001)				
per year	467.0	253.7	167.0	67.1
per 100,000 inhabitants	45.1	31.9	18.7	15.3
per 1,000 employees[f]	1.16	0.94	0.53	0.42
per 1,000 natural scientists and engineers[f]	32.0	38.1	21.0	17.3

[a] Engineers and natural scientists in Dresden: 1996-2000.
[b] Includes all firms with at least one employee.
[c] Employees with tertiary education in natural science or engineering.
[d] Includes research universities and technical colleges ("Fachhochschulen").
[e] Includes three groups of scientific disciplines: natural sciences, agricultural and nutritional sciences, and engineering. Excludes medical sciences, cultural and social sciences, law and economics, and arts.
[f] Total of private and public sector.
Source: German statistical office (population, university staff); establishment file of the German social insurance statistics (firms, employees); German patent office (patents).

Why do we stress this point? Most patents refer to technical solutions applicable in the fields of natural science and engineering. Performing research with a patentable output normally requires skilled experts in these fields. Yet the number of natural scientists and engineers employed is a reasonable proxy for the regional pool of potential inventors.[2]

In a similar way the scientific staff at universities in natural sciences and engineering disciplines is interpreted as the pool of potential academic inventors. Again, Dresden shows the most distinctive orientation towards these fields most likely to generate academic patents. In absolute figures the number of university natural scientists and engineers in Dresden is twice as high as in Halle which ranks second. In all regions the pool of potential inventors at universities is of significant size compared to the respective private sector pool (between 16% in Halle and 23% in Rostock).

Relating patent numbers to the numbers of potential inventors results in patent efficiency measures as reported in the last section of table 1. A clear divide between the leading regions of Dresden and Jena on the one side and the lagging regions of Halle and Rostock on the other side can be observed. The three different measures of patent effi-

[2] In fact the number of private sector natural scientists and engineers turns out to be highly significant in explaining regional patent output (Fritsch and Slavtchev, 2005).

ciency can be read as a step-by-step approximation to the relevant input pool as reference for patent output. Patent density, defined as patents per capita, shows a clear lead of Dresden followed by Jena, Halle, and Rostock. With an average yearly patent density of 45 patent applications per 100,000 inhabitants Dresden is ranked somewhere in the middle of all German planning regions (Greif and Schmiedl, 2002). The order between the regions is left unchanged, but with Jena moving closer towards Dresden and away from Halle, if employees are used as a more appropriate measure of innovative potential. Finally, if we apply the number of natural scientists and engineers that we assume to best represent the pool of potential patent inventors Jena takes the lead from Dresden and the gap between the leading regions and Halle and Rostock widens.

This short inspection of the regions' innovative potential and performance revealed two main results: First, Dresden is the region with the largest potential to generate patents both in terms of the share of natural scientists and engineers and in terms of their absolute number. Second, natural scientists and engineers in Jena exhibit the highest patenting productivity though Jena's pool of potential inventors relative to all employees is not larger than in Rostock and is still smaller than in Halle in absolute figures.

To explain these differences in patenting efficiency the theory of innovation systems suggests to investigate the relationships between the actors involved in regional innovative activity; especially, how easily they allow knowledge flows between the actors as the key prerequisite for generating higher innovative output. In the following section we construct networks of personal relationships between patent innovators which can be interpreted as channels of knowledge transfer. The characteristics of the networks as a whole, and the special role of public research organizations within them, will be presented and used to derive some possible explanations for the observed regional differences in innovative performance.

3 Regional Innovator Networks and the Role of Research Institutions

3.1 Patent data and social network analysis

There is a growing number of studies in which patent information is used to apply social network analysis in the economics of innovation. Most authors link the inventors of the patents directly (Balconi et al., 2004; Fleming et al., 2004a,b) and some link the assignees via common inventors (Breschi and Lissoni, 2003; Singh, 2003, 2004; Cantner and Graf, 2006). We pursue the latter approach to map the regional networks of innovators and analyse patent applications at the German Patent Office which were disclosed from 1995 to 2001. The regional assignments of patents are based on the inventors' residence; i.e., we use all patent applications with at least one inventor residing in the respective region to build the networks.

On each patent application we find information about the applicant (innovator) and the persons involved in the process of development of the patent, the inventors. We assume two innovators to be related if at least one inventor has developed a patent for both innovators. In practical terms this means that a relation is established between A and B if we find an inventor on a patent by A and on a patent by B. There are two possibilities of how this might appear:

1. The innovators are joint assignees of the same patent. In this case we assume a previous research *cooperation*.

2. The same inventor is named on two distinct patents assigned by different innovators. In this case we assume *mobility* of the inventor between the innovators.[3]

As these two cases are quite different from each other we analyse them separately throughout the paper and combine them to the network of personal relationships whenever it seems appropriate.

The sub-sample of public research includes the following organizations: research universities, technical colleges ("Fachhochschulen") and non-university scientific institutes. The latter are in most cases members of one of the big German scientific societies: the Max-Planck society, the Leibniz society and the Fraunhofer society. In addition we include a heterogeneous group of research organizations which are in many cases the successors of former socialist applied research institutes with close ties to industrial R&D. To enter the group of public research applicants an organization had to rely at least partly on public funds to finance its regular budget.

3.2 Patent data from research institutions: critical remarks

Until 2002, the German patent law had the speciality that university professors had the right to patent for their own account and not under the name of their university. In private firms as well as in non-university public research organizations the intellectual property rights connected to employees' inventions have always been in possession of the employer. As our data refer to a period previous to 2002 the number of university patent applications is underestimated. In refining the database we made an effort to compensate this bias by checking each individual applicant with a professor's degree as part of his name if he or she was enrolled at one of the regional universities within the inspected period. If this was confirmed the patent was added to the respective university's account.

The number of patent applications from public research is further underestimated because intellectual property rights are often traded against financial support. In university-industry cooperation projects, the private firm sponsors the research carried out in the

[3]Mobility, in this definition, includes also cases of inventors contracted by different innovators without actually being their employee, e.g., consulting inventors.

Table 2: Data description

	Dresden	Jena	Halle	Rostock
Patents				
Number	3,269	1,776	1,169	470
Co-applications	343	237	154	93
Share of Co-applications	10.5%	13.3%	13.2%	19.8%
Patents by Private Applicants	2,552	1,378	1,050	438
Patents by Public Applicants[a]	874	527	148	67
share of private patents	74.5%	72.3%	87.6%	86.7%
share of public patents	25.5%	27.7%	12.4%	13.3%
Actors				
Applicants	1,132	679	538	350
private	1,078	629	511	336
public	54	50	27	14
Inventors	4,127	2,686	1,682	614

[a] Private and public patents do not sum up to total number since they are double counted in cases of more than one assignee.

university's lab but claims the exclusive right to patent the invention in exchange. In consequence there is not only an underestimation of public research patent activity. Even more important, a number of university-industry cooperations leading to patent output escape from being counted as cooperations.

Another issue related to public research patenting is headquarter application: Like big private companies universities have their patenting activities centralized. They appear as monolithic actors but in fact the inventions are made in the departments. Because of disciplinary boundaries it can not be assumed that there are steady knowledge flows between the departments. Therefore, if two actors both maintain patent relationships with the same university this does not ensure that information is transferred between these two actors through the university.

3.3 Graphical analysis

Before we investigate the network visualizations, some basic comparative statistics of the four regions are given in table 2. The first observation is that the regions differ strongly in the level of overall patent activity. Dresden displays 3,269 applications during the 1995-2001 period or 467 applications per year. Jena ranks second with slightly more than half of the Dresden value, followed by Halle (36% of the Dresden value), and Rostock (14%).

A second observation regards the differences in the importance of public research. In Dresden and Jena public research organizations account for more than one quarter of all patent applications. Halle and Rostock show about half this value. Compared to other German regions these figures are very high. According to Greif and Schmiedl (2002) in the period 1995-2000 only Berlin and Munich filed more patents from public research than Dresden, while Jena is ranked 6th. Among all 97 German planning regions Dresden and

Jena show the highest share of public research in all patent applications.

The high share of cooperations in Rostock is striking but probably due to the lack of corporate applicants and the accordingly high share of inventor applications. Cooperative research then leads to co-applications where in other regions the co-researchers are more likely to work for the same single employer applicant.

In the following, we shortly describe the specificities of each of the four networks before we compare the regions over the whole period and their development over time. The visualizations of the regional networks of innovators (figure 1 to figure 4) show the networks of personal relationships – cooperation and scientist mobility combined – over the whole seven-year period 1995-2001. Each innovator is represented by a node, where public research institutions are represented by square-shaped nodes and private firms or individuals by circles. The size of a node is proportional to the number of patents filed by the respective actor. Edges between the nodes represent cooperative relationships by joint patent application (blue) or relationships by scientist mobility through joint inventors (red). If two assignees have both types of relationships edges are black. The width of the edges is proportional to the number of relations between the respective actors. The position of nodes and the length of the edges is produced by multidimensional scaling with node repulsion and equal edge length bias as layout in NetDraw (Borgatti et al., 2002). A direct interpretation is of course difficult but more central actors are generally positioned at the center of the network.

For each region detailed information about the most active patentees and their ranking is given in tables 8 to 11 in the appendix.

Dresden The innovator network of Dresden (figure 1; only the main component is shown) can be characterized as bi-polar. It is dominated by two big public research organizations, the Fraunhofer Society and the Technical University (TU) Dresden, with highest ranks in terms of centrality and the number of patents filed. Koenig & Bauer, a printing press manufacturer, has filed even more patents but ranks only 15th in terms of centrality (see table 8). This company should be seen as a special case due to the fact that its products, huge printing machines for newspapers, often have the character of singular devices adapted to each customer's special needs where each single step of adaptation seems to be patentable. As all patents generated by one of the eleven Fraunhofer institutes located in Dresden are filed centrally at the society's headquarters in Munich, we can not distinguish between different institutes. Taken as a single entity these institutes appear as something like a second technical university (between whose departments we can not differentiate either) covering many fields of research especially in engineering disciplines.

The two central actors are strongly connected both by cooperative relationships and by scientists moving from one organization to the other. Each pole is the central actor of a subnet mainly consisting of private firms. The Fraunhofer subnet seems to be more tightly interconnected and more cooperative than the TU Dresden subnet. Between the

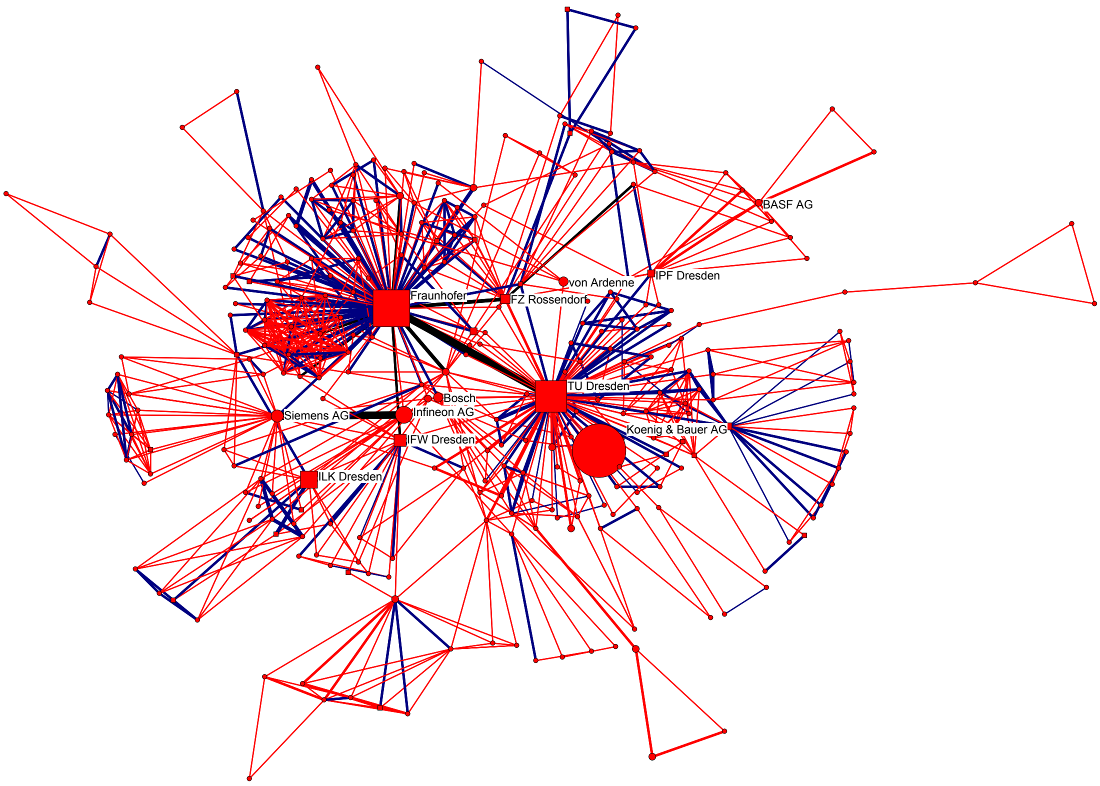


Figure 1: Main component of Dresden 1995-2001. Isolates and pendants removed, cooperations - blue, scientist mobility - red, both - black

two subnets there are only few linkages. While there are some intermediates like the Rossendorf Research Institute (FZ Rossendorf) and the Institute for Solid State and Materials Research (IFW Dresden) most of the connections between the subnets stem from direct relations between the two big research organizations.

Seven out of the ten most central patentees are public research organizations including the technical college (HTW Dresden) in the TU Dresden subnet and the Institute for Air-conditioning and Refrigeration Engineering (ILK Dresden) with a more independent position (see table 8 in the appendix). The other three are Siemens, Infineon, and Bosch. The very strong connection between Siemens and Infineon is due to the fact that Infineon is a 1999 semiconductor spin-off from Siemens.

Jena Different from Dresden, the network of innovators in Jena (figure 2; only the main component is shown) is multi-polar. The most active patentee is a private firm, Carl Zeiss, which is a successor of the former 'Kombinat' VEB Carl Zeiss which dominated the economic structure of Jena during the socialist era in the GDR. Carl Zeiss also ranks high in terms of centrality but the most central actor of the network is the university (FSU Jena), followed by two public institutions of applied research, the Institute for Physical High Technology (IPHT) and the Fraunhofer Institute. In contrast to Dresden private companies such as Carl Zeiss, Jenoptik (another successor of the Kombinat), Jenapharm,

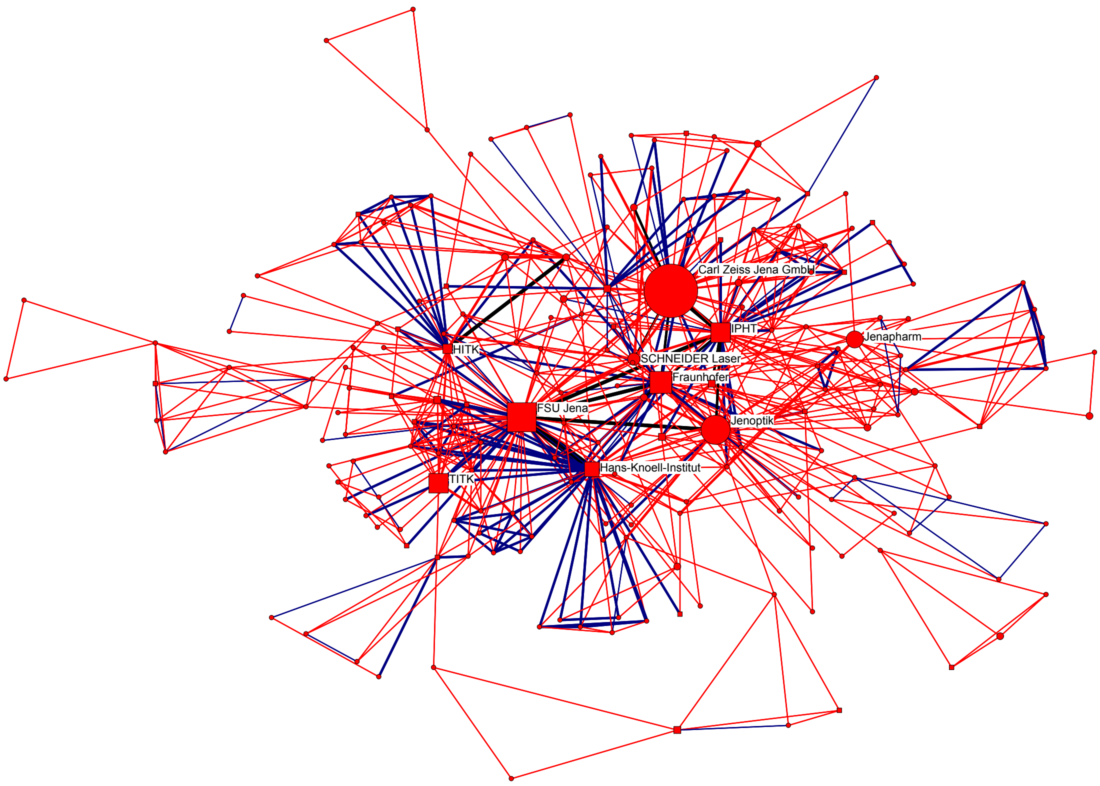


Figure 2: Main component of Jena 1995-2001. Isolates and pendants removed, cooperations - blue, scientist mobility - red, both - black

and Schneider Laser are clearly visible actors and tightly connected within the network. The same holds for non-university research institutes like the Hermsdorf Institute for Technical Ceramics (HITK), the Thuringian Institute for Textile and Plastics Research (TITK), and the Hans-Knoell Institute. The latter is interesting as it is mainly linked through cooperative relationships. The linkages between all the central actors are dense and no separated subnets can be identified. The intuition from the picture supports the assumption that Jena's lead in terms of patent efficiency might be the result of intense knowledge flows within the region's network of innovators.

Halle In Halle (figure 3), Buna Sow Leuna, with 142 patents and rank 1 in centrality, is the dominating actor, followed by Martin-Luther University (MLU Halle-Wittenberg), the only research organization of importance, and the former Leuna-Works (table 10). In 1995, Dow Chemical took over the former Buna-Works whereas Leuna was split up into several smaller firms, like KataLeuna, Chemtec Leuna, and RMH Polymers. Strong (red) ties between Leuna and its successors indicate that former Leuna researchers often work for (or are the founders of) the smaller firms which developed from former Leuna departments. The third important location of chemical industry, Bitterfeld-Wolfen, has its own subnet, too. The main actor here is FEW Chemicals. The ties between the three locations are not prominent. The university is connected with Buna Sow Leuna

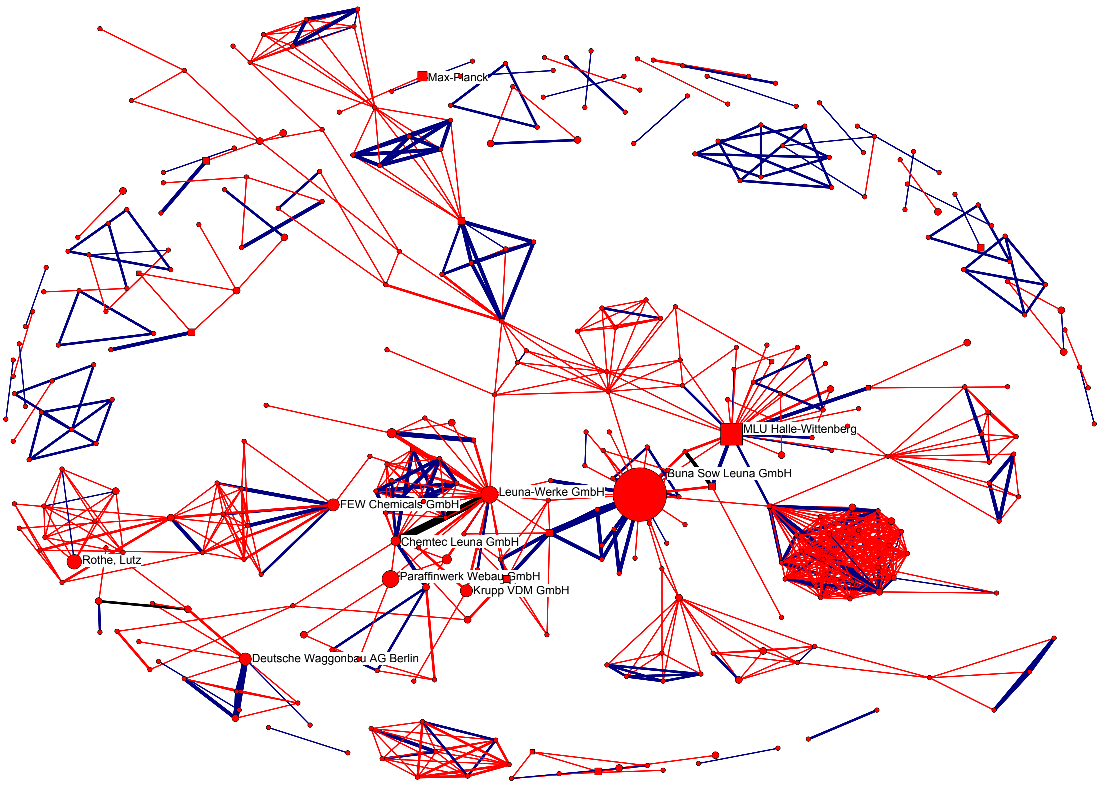


Figure 3: Network of Halle 1995-2001, isolates removed, cooperations - blue, scientist mobility - red, both - black.

but does not have direct ties with the Leuna or the Bitterfeld complex. The Leuna-Works assign for patents only until 1996, the year when Buna Sow Leuna appears in the list for the first time. At large, the innovator network of Halle is more fragmented than those in Dresden and Jena, the actors forming the main component are organized in subcomponents connected only through a few bridging actors ("cutpoints") which makes the network vulnerable to breakup.

Rostock In Rostock patent activity is dominated by the Rostock university as the center of the main component. The university displays many cooperative (blue) links to individual applicants which is partly in consequence of the data refinement procedure by which individual applications of professors were assigned to the university. Presumably these professors often set their staff as co-applicants resulting in cooperative links between the university and these staff members which are in fact intra-university relationships. But we cannot correct for this as it is nearly impossible to verify these persons as former university staff. Around the university a number of applicants are biotech firms indicating some progress towards the officially promoted new focus on biomedical sciences. Engineering disciplines close to industries traditionally located in the region like machinery and shipbuilding do not play a prominent role in the main component around the university but still live on in the smaller components. Compared to the three other

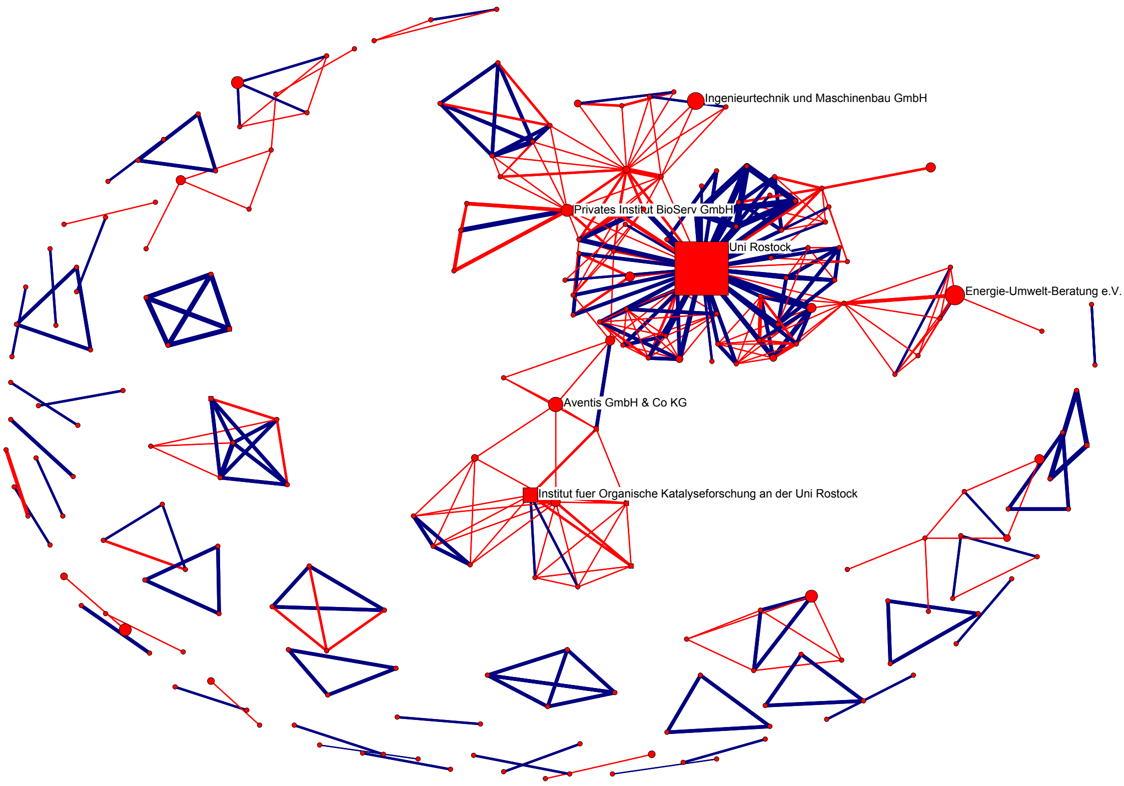


Figure 4: Network of Rostock 1995-2001, isolates removed, cooperations - blue, scientist mobility - red, both - black.

regions, the innovator network in Rostock is very small in size and faces a severe lack of private firm R&D.

3.4 Comparative network structures

Static analysis

The network visualizations presented above show only the largest component of the networks of Dresden and Jena. General characteristics of the complete networks for the whole 1995-2001 period are given in table 3.

Looking at the most comprehensive type of network, the network of personal relationships (pr), we find that the main component integrates between 25% (Rostock) and 37% (Jena) of all innovators. This order between the four regions is mirrored when it comes to the share of isolated innovators where, however, the inter-regional variation is lower. Assuming that knowledge flows only occur between connected actors, in Jena more actors can participate in the sharing of common knowledge. The Jena network integrates the highest share of innovators into the largest component and at the same time leaves the lowest share isolated. Rostock, in contrast, is least able to exploit its networking potential in terms of the share of actors in the largest component. The absolute size of the largest component is of course highest in Dresden.

Table 3: Network Statistics (1995-2001)

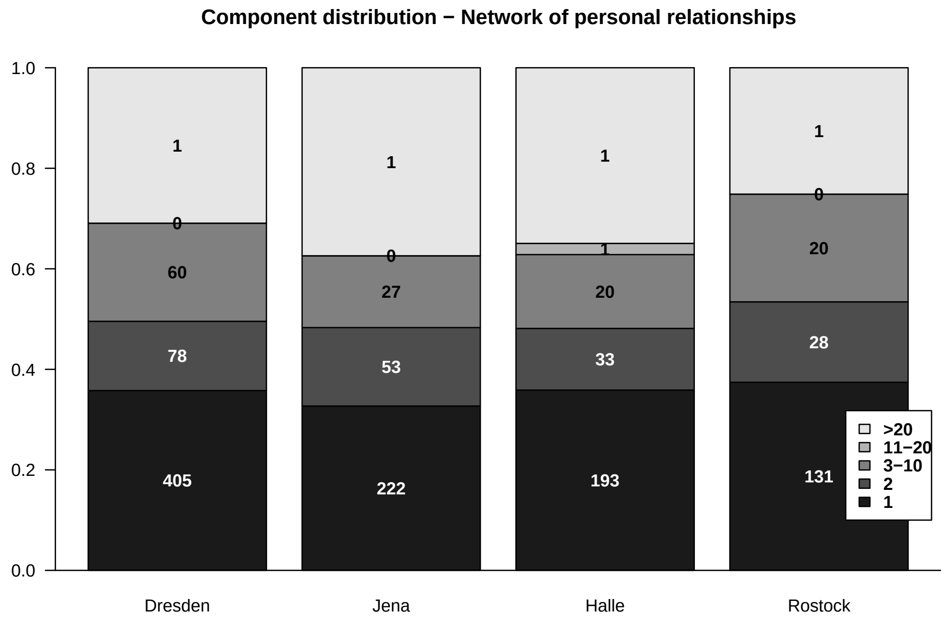
	Dresden			Jena			Halle			Rostock		
	pr	ko	sm	pr	ko	sm	pr	ko	sm	pr	ko	sm
Nodes	1132	1132	1132	679	679	679	538	538	538	350	350	350
Number of components	544	790	698	303	457	388	248	386	309	180	231	241
Size of largest component	350	136	302	254	102	236	188	22	164	88	43	64
Share in largest component	30.9%	12.0%	26.7%	37.4%	15.0%	34.8%	34.9%	4.1%	30.5%	25.1%	12.3%	18.3%
Isolates	405	656	629	222	374	355	193	316	283	131	180	222
Share of isolates	35.8%	58.0%	55.6%	32.7%	55.1%	52.3%	35.9%	58.7%	52.6%	37.4%	51.4%	63.4%
Network centralization	0.094	0.052	0.067	0.114	0.037	0.098	0.050	0.021	0.048	0.144	0.118	0.046
Density	0.004	0.003	0.002	0.010	0.006	0.004	0.011	0.006	0.005	0.014	0.010	0.005
Mean degree	5.083	3.081	2.002	6.483	3.935	2.548	6.093	3.230	2.862	5.034	3.434	1.600
Mean degree (binary)	2.231	0.820	1.429	2.695	0.919	1.817	3.022	0.803	2.230	2.200	1.006	1.194

To analyse the cohesiveness of a network, density is a widely used measure. If g is the size of the network as measured by the number of actors and d_i is the degree, i.e. the number of connections, of actor $i, i = 1, \ldots, g$, then the density D of the network is defined as the number of all linkages divided by the number of possible linkages within the network $D = \sum_{i=1}^{g} d_i/(g^2 - g)$. This measure is somewhat problematic in comparing networks of different sizes as the number of possible linkages increases geometrically while the actual number of linkages usually does not. Therefore, we also report the mean degree, i.e. the average number of ties, of the networks based on the actual number of connections and based on the dichotomized (binary) networks to account for the number of related actors. With a mean degree of 6.483, the actors in Jena are more interrelated than actors in the other regions. If we look at the number of linkages not accounting for the intensity (based on the binary network), we find the actors in Halle to be connected to more different actors than elsewhere. If we distinguish between the types of relations, we find that in Halle there are especially linkages through scientist mobility, which is probably rather due to the reorganization processes mentioned above than to mobility in our – idealized – interpretation.

With respect to the centralization of the networks[4], we observe Rostock to come closest to the extreme of a "star". As the university is the only larger actor, this result is not really surprising. It is followed by Jena with a clear core-periphery structure and Dresden, which is slightly more dispersed. The graphical impression of Halle corresponds well to the low centralization in this network where the large actors are lined up like pearls on a string.

We analyse the size distribution of components in figure 5. A common feature of all networks is the existence of a single main component which is at least ten times larger than the second largest component with a maximum size of 12 innovators in Halle and no more than 10 in the other regions (figure 5). This is remarkable as we do not differentiate between technological fields. The tendency to connect to a giant component does not seem to be hindered by the boundaries of disciplines. In all regional networks we also observe a considerable 12 to 16% of paired actors. To qualify pairs of innovators as

[4]The degree centrality of actor i is the number of its ties divided by the number of possible ties $C_i = d_i/(g-1)$. The *network centralization* is then given by $C = \sum_{i=1}^{g} (\max(C_i) - C_i)/(g-2)$.



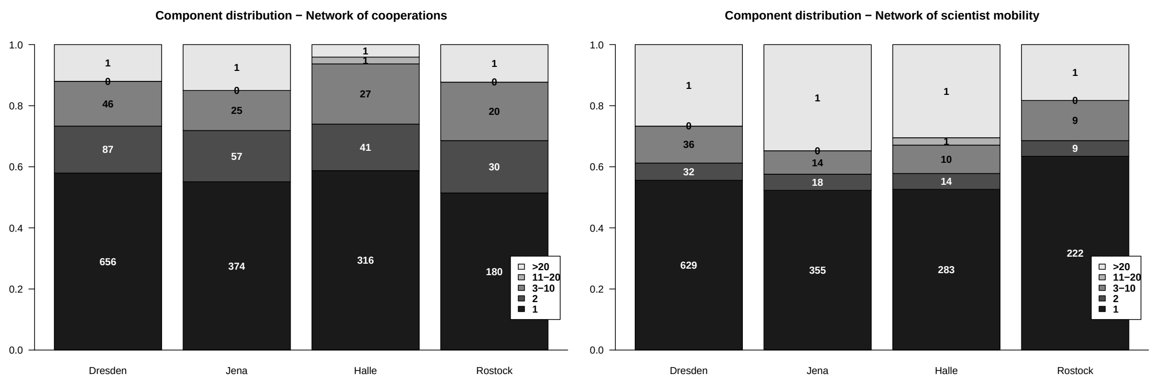
Note: Numbers on bar segments indicate the number of components of respective size.

Figure 5: Component Distribution 1995-2001

networking entities is obviously difficult to justify. Sticking to the components with at least three connected actors reveals that in Dresden, Jena and Halle half of the patentees are embedded in one of these sub-networks. In Rostock the share is slightly lower.

So far the network of personal relationships was under inspection. As it combines both relationships based on joint application of patents and relationships based on scientist mobility, we now disaggregate these relationships to investigate them separately in figure 6.

In the network of personal relationships some actors are connected only by a combination of cooperative (blue) and mobility (red) relationships. These paths are broken up if we inspect exclusively cooperative, or mobility, relationships. By definition, this leads to smaller main components. But the extent to which the "combined" main component drops in size is dependent on the type of relationship. If innovators are linked only by scientist mobility the largest components show up only slightly smaller. In Jena the main component still includes 93% of its original actors. Even in Rostock the main component is no less than 73% of its original size. If, on the other hand, only joint patent application is allowed to build the network the main components drop sharply in size and comprise about half the original actors in Rostock and around 40% in Jena and Dresden. In Halle, the main component is only a 12% fraction of the combined main component. With 22 versus 12 patentees the difference between the largest and the second largest component has nearly disappeared so that it is hard to speak of a main component of cooperative relationships in Halle at all.



Note: Numbers on bar segments indicate the number of components of respective size.

Figure 6: Component Distribution – Network of cooperations and network of scientist mobility – Period 1995-2001

It turns out that scientist mobility is more powerful in connecting innovators than joint patenting. This is because the mobility type of relationship is more open and less formal: The innovators do not have to cooperate. They do not even need to know each other. It is only the inventor moving from one employee (or, more general, applicant) to another that constitutes the link between the innovators. In contrast to cooperative patenting reciprocity is not necessary. Instead, scientist mobility can even constitute a link between applicants of patents filed at opposite ends of the time period under inspection. Nevertheless those mobility relationships can still be a channel of knowledge transfer.

It is not only the main component that makes the difference between the two types of networks. The networks of cooperation are generally more scattered than the networks of scientist mobility. The share of isolates is slightly higher (exception: Rostock), and especially the share of pairs of innovators is about three times higher than in the networks of mobility (15-17% compared to 5-6%). In many cases, two actors just decide to file one or more joint patent(s) but do not have patent cooperations with other actors within the period under inspection. On the other hand if assignees are connected through joint inventors it is less probable that only two assignees are involved (because inventors are very mobile or innovators have many inventors switching at least one time). In consequence, only between 26% and 31% of all patentees cooperate in networks with at least three persons but 31% to 42% are linked by scientist mobility in networks of at least three persons.

Network dynamics

In general, the structure of the types of networks we analyse is highly dependent on the assumptions about the longevity of personal relations. In choosing a period from 1995 to 2001, we implicitly assume that after seven years of having worked together, there are still connections between inventors. To check for the robustness of our results, we therefore

Table 4: Network statistics - Network of personal relations - Sub-periods

	Dresden			Jena			Halle			Rostock		
	P1	P2	P3	P1	P2	P3	P1	P2	P3	P1	P2	P3
Nodes	527	535	613	281	367	398	238	273	300	137	152	211
Number of components	312	323	355	161	212	203	130	160	181	81	88	116
Size of largest component	79	95	138	60	79	122	24	41	27	29	27	34
Share in largest component	15.0%	17.8%	22.5%	21.4%	21.5%	30.7%	10.1%	15.0%	9.0%	21.2%	17.8%	16.1%
Isolates	234	245	276	122	161	156	98	125	137	63	61	83
Share of isolates	44.4%	45.8%	45.0%	43.4%	43.9%	39.2%	41.2%	45.8%	45.7%	46.0%	40.1%	39.3%
Network centralization	0.070	0.060	0.081	0.056	0.073	0.101	0.065	0.039	0.053	0.160	0.126	0.122
Density	0.007	0.006	0.006	0.014	0.012	0.013	0.020	0.014	0.014	0.030	0.022	0.020
Mean degree	3.556	3.110	3.667	4.000	4.431	5.171	4.681	3.780	4.253	4.117	3.382	4.246
Mean degree (binary)	1.423	1.196	1.409	1.495	1.520	1.965	1.714	1.546	2.167	1.620	1.289	1.716

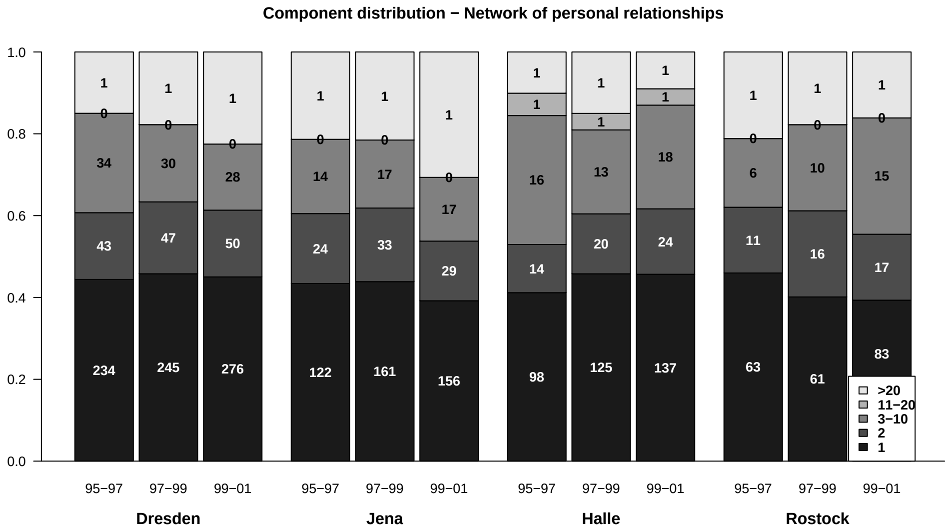
also analyse shorter time spans of three years. In dividing the sample period into three overlapping sub-periods of equal length, 1995-1997 (P1), 1997-1999 (P2), and 1999-2001 (P3) we can also inspect network dynamics. In the following we restrict ourselves to the network of personal relationships (table 4 and figure 7)

First of all, the regional networks have grown in size. The number of nodes in later periods is always higher than in the preceding period. Whereas in Jena and Halle growth was higher between the first and the second period, Dresden and Rostock grew faster between the second and third period. Looking at the development over three periods, Rostock, starting at the smallest network size of 137 assignees in the first period, made the greatest step forward with a 54% growth in the number of patentees. Jena, although starting at a size twice as big as Rostock, still realized a growth in the number of assignees of 42% which is also the greatest absolute increase (+117). Halle started with a size not much smaller than Jena and grew only by 26%. In Dresden the number of patentees grew only by 16%. Taken into account that Dresden has by far the largest pool of innovators, which decreases relative growth given the same absolute increase, the dynamic is still significantly lower than in the Jena region.

The number of assignees is only the networking potential. The development of the largest component over time gives some hint about how network structure changes from period to period. In Jena the share of the largest component in all network actors does not change between the second and the first period despite of significant growth in the number of patentees. The potential seems to be realized in the following period when the share of the largest component in all actors rises impressively from 22% to 31% (a rise of 54%).

In Dresden the share of the largest component rises continuously but only up to a level of 23%. Both Jena and Dresden manage to increase integration into the main component despite a simultaneously growing number of actors.

In Halle and Rostock the main component of the third period does not integrate as many actors as in the first period. In Halle, despite a relatively slow growing number of actors, the share of the largest component drops from 10% to 9%. Besides this development, the absolute figures in Halle are of special interest. When analysing the whole period, there is almost no difference between Halle and Jena with respect to this measure.



Note: Numbers on bar segments indicate the number of components of respective size.

Figure 7: Component distribution - Network of personal relationships - Sub-periods

When splitting the period, we find the largest component in Halle to be broken up which documents the fragility of this network mentioned above. In Rostock, a fast growing number of patentees can not fully be integrated into the main component at the same time. This leads to a decrease in the share of main component from 21% in the first to 16% in the third period.

If we compare the first and the last period, we observe an increasing centralization in Dresden and Jena, while the networks in Halle and Rostock become less dominated by few main actors. The mean degree increases significantly only in Jena (from 4.0 to 5.2) and remains almost constant in Dresden and Rostock while it decreases in Halle. If we only count the related actors but not the intensity of the link, we find an increasing mean degree in all regions except for Dresden.

To summarize our descriptive results, we can state that all four networks have grown but the structural differences between regions are evident: i) only Dresden and Jena manage to integrate an increasing share of actors in the largest component; ii) the average number of linkages is only increasing in Jena; iii) Dresden and Jena become more centralized while Halle and Rostock become more dispersed; iv) Dresden and Jena are especially dominated by public research. Dresden is a bi-polar network especially dominated by public research, in Jena a group of core actors is well-balanced between public research and private firms, in Halle there are large firms dominating and in Rostock there is a rather central university and a mixture of individuals and smaller patenting firms.

It seems as if there is a relationship between the prevalence of valuable public research and the connectedness of local innovator networks. To assess this relationship in greater depth, we now turn to the specific role of public research.

4 Research Institutions as Distinguished Network Actors

To assess the importance of public research for local innovation activity based on patent data one fundamental point has to be stressed in the beginning. As said in section 2 patents are granted for new solutions to technical problems. To produce patentable knowledge a scientific discipline has to be in principle applicable and technical in nature. Therefore large university faculties like social sciences, cultural studies, and arts, though potentially of considerable importance for a region's economic success by providing organizational know-how and creativity (Florida, 2002), are not within the scope of this investigation. The same holds for research institutes explicitly designed to perform basic research, namely the Max-Planck institutes: Despite being well-funded and staffed they hardly show up in the networks of innovators based on patent information. In contrast, the Fraunhofer institutes, with their mission of applied research and the need to partly finance from contract research for private firms, are important patentees.

Furthermore, even if we concentrate on the fields of research where patent output is to be expected networks built from patent relations still reflect just a fraction of the interaction actually going on between public research and private firms. Aside from measurement problems already discussed in section 3 this is because a wide variety of informal contacts as well as contract research activities just do not lead to (and are not aimed at) patent output.

The above-mentioned points hold for purely private relationships as well but to a lesser extent: As they are forced to survive in the market private firms perform generally more applied research and have higher incentives to protect results from R&D by patents. In consequence, when interpreting the role of public research within networks of patent innovators we should keep in mind that their importance is systematically underestimated both in terms of the absolute amount of knowledge transfer and relative to exclusively private relationships.

For a first picture of the public research landscape, we provide information about the funding of local universities and technical colleges in table 5. To compare their orientation towards natural sciences and engineering we report absolute figures as well as the respective shares of these fields of study. Further, we distinguish external funding with respect to the source, where funding from firms is an indicator of market oriented research and the motivation to cooperate with actors outside academia. Funding from the federal government and the DFG (National Science Foundation in Germany) can serve as an indicator of the quality of academic research.

In general, the technical colleges have much smaller budgets and rely less on external funding than the co-located universities. The higher share of the budget devoted to natural sciences and engineering indicates their more technical orientation. We also observe an overall high share of natural sciences and engineering in the acquisition of external funding.

Table 5: External funding and patenting of research universities and technical colleges (TC) in the four regions (1,000 EUR; 1994-2000 mean yearly values).

	TU Dresden (University)	HTW Dresden (TC)	FSU Jena (University)	FH Jena (TC)	MLU Halle (University)	FH Merseburg (TC)	Uni Rostock (University)
Total budget funds	542,717	34,953	424,095	28,426	421,659	23,382	321,905
Share of natural sciences and engineering[1]	*30%*	*57%*	*16%*	*24%*	*15%*	*30%*	*14%*
External research funds	61,343	1,983	24,505	431	23,363	979	16,155
Share of natural sciences and engineering	*79%*	*91%*	*50%*	*62%*	*56%*	*81%*	*53%*
Share of external research funds in total budget	*11%*	*6%*	*6%*	*2%*	*6%*	*4%*	*5%*
Funds from federal government and federal states	26,998	589	7,367	94	8,290	291	6,871
Share in total external research funds[2]	*44%*	*30%*	*30%*	*22%*	*35%*	*30%*	*43%*
Funds from German Science Foundation (DFG)	13,778	80	8,978	50	8,954	110	4,757
Share in total external research funds	*22%*	*4%*	*37%*	*12%*	*38%*	*11%*	*29%*
Funds from private firms	13,518	1,142	4,640	150	3,344	523	2,961
Share in total external research funds	*22%*	*58%*	*19%*	*35%*	*14%*	*53%*	*18%*
Funds from other external sources[3]	7,048	172	3,520	137	2,774	54	1,565
Share in total external research funds	*11%*	*9%*	*14%*	*32%*	*12%*	*6%*	*10%*
Patent applications (1995-2001)	231	18	115	3	47	5	45
Share in regional patenting	7.1%	0.6%	6.5%	0.2%	4.0%	0.4%	9.6%
Co-applications	27	8	30	3	10	3	30
Share in all patent applications	11.7%	44.4%	26.1%	100.0%	21.3%	60.0%	66.7%

[1] Includes three groups of scientific disciplines: natural sciences, agricultural and nutritional sciences, and engineering. Excludes medical sciences, cultural and social sciences, law and economics, and arts.
[2] External research funds from different sources are not reported separately for disciplines.
[3] Includes funds from international organizations (EU, OECD, etc.), foundations, municipalities, the national labour office, and other public organizations.
Source: German federal statistical office.

If we analyse the sources of external funding more deeply, we find the technical colleges to rely more on funding from private firms compared to the universities which receive most of the external funding from the state and the DFG. All these figures show that the role of the technical colleges is different from the universities in the sense that research in universities is more oriented towards fundamental insights, whereas technical colleges are more application oriented.

This orientation towards applied research also shows up in the co-applications of patents. Obviously, the high shares of firm funding in technical colleges compared to universities correspond to higher shares of co-applied patents. Overall, universities patent more frequently than the technical colleges and play a major role in regional patenting as documented by a share between 4% in Halle and 9.6% in Rostock. While these figures give us a hint about the importance of public research in regional innovation systems, we are now interested in the more specific role in the transmission of knowledge, i.e. their integration in the local network of innovators.

We already introduced the measure of centralization in section 3. This property of a whole network is an aggregation of individual measures of centrality which can be calculated in different ways. We now look at the individual measures and restrict ourselves to the centrality based on degree and on betweenness. While the degree-based centrality measure provides us with an idea of how connected an actor is, the betweenness measure tells us how important an actor is for knowledge flows between different actors and therefore for the connectivity of the network as a whole. In the appendix, we report rankings based on both centrality measures of the most active patent applicants in the four regions for the networks of cooperation, scientist mobility and its aggregate – personal relationships. In the second column of each table (8 to 11), we indicate whether an actor is a public research organization or not. From a glance at these tables it becomes apparent that Dresden and Jena are dominated by public research[5], while in Halle and Rostock this is not so clear. For a first systematic approach to the differences between public and private actors in terms of centrality, we calculate averages for each type in table 6. It becomes rather clear, that in all regions and for all types of networks the public actors are more central than the private ones according to degree as well as betweenness centrality.

Of course, centrality is not independent of the size of the innovators. Larger actors should have more cooperations and more linkages through mobility. Public research institutes are in general larger than the average innovator, which might lead to our observation of a higher centrality of public research. To control for this effect, we perform a simple OLS regression with the degree centrality as the dependent variable in table 7. The independent variables are a dummy variable for public institutions (Public) and a proxy for size. Since we cannot observe size directly, we approximate size by the number of patents filed by each innovator (Patents). In all regressions, the number of patents has a

[5]Within the top ten central actors there appear only three (Dresden) and two (Jena) private actors respectively.

Table 6: Centrality of public and private actors – mean comparison

	degree		betweenness[a]	
	Private	Public	Private	Public
Network of personal relations				
Dresden	4.2	22.2	89.2	3389.3
Jena	4.8	27.3	96.6	1485.0
Halle	5.8	12.6	146.0	1279.9
Rostock	4.5	18.1	22.5	527.6
Network of cooperation				
Dresden	2.5	15.2	3.5	656.3
Jena	2.8	17.7	6.9	355.5
Halle	3.0	7.1	1.0	21.1
Rostock	3.0	14.2	0.1	118.3
Network of scientist mobility				
Dresden	1.8	7.0	114.3	2406.8
Jena	2.0	9.6	108.3	1219.3
Halle	2.7	5.5	131.1	705.2
Rostock	1.5	3.9	25.7	198.6

[a] dichotomized networks

significant explanatory power for centrality. In Dresden and Jena the positions of public research are also significantly more central than those of private actors. In Halle this only holds for the overall network of personal relations and the sub-network of cooperation while in the subnet of scientist mobility the coefficients of the Public dummy are positive but not significant at a level of 5%. In Rostock public actors are more central than their private counterparts in all networks, too, but again, the differences are not significant at 5%.

Why are public research organizations still more central network actors even if size differences have been taken into account? First, what really matters may be not size but the diversity and variety of research conducted, which makes them a promising knowledge source for a great number of very differently specialized private firms. This holds especially for the big research universities that are by definition 'universal'. Second, public research organizations might be more willing to cooperate and share their knowledge. This would be in line with Dasgupta and David's (1994) concept of 'open science' where disclosure and diffusion of research results is seen as the original mission and fundamental norm of public research. This again holds first of all for universities. Third, and less idealistic, it may just be the need for finance that lets public research seek for contract research partners. This is most urgent for non-university public research institutes, e.g., the institutes of the Fraunhofer society, which are only partly supported by public funds. Patent cooperations can then be seen as aiming on joint marketing of new knowledge. Public research organizations act as substitutes for private research service providers and the observed patent relations are just tracing their business relationships.

Table 7: OLS-Regression - Dependent variable: Degree centrality

	Network of personal relations				Network of cooperation				Network of scientist mobility			
	Dresden	Jena	Halle	Rostock	Dresden	Jena	Halle	Rostock	Dresden	Jena	Halle	Rostock
C	5.883	4.513	8.626	0.234	3.194	2.872	4.511	-1.459	2.689	1.640	4.115	1.693
	(0.000)	(0.000)	(0.000)	(0.804)	(0.000)	(0.000)	(0.000)	(0.088)	(0.000)	(0.000)	(0.000)	(0.000)
Public	22.544	27.769	9.323	7.786	16.266	20.337	5.794	6.006	6.277	7.432	3.529	1.780
	(0.000)	(0.000)	(0.006)	(0.065)	(0.000)	(0.000)	(0.010)	(0.114)	(0.000)	(0.000)	(0.079)	(0.319)
Patents	0.976	2.078	1.201	5.393	0.667	1.135	0.645	4.580	0.309	0.943	0.557	0.813
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
R^2	0.381	0.624	0.227	0.523	0.322	0.468	0.161	0.491	0.289	0.656	0.147	0.125
adj. R^2	0.380	0.623	0.224	0.520	0.321	0.466	0.158	0.488	0.288	0.655	0.144	0.120
Obs.	1132	679	538	350	1132	679	538	350	1132	679	538	350

P-values in parentheses

5 Conclusion

This work is an exploratory study with the goal to analyse differences between regional innovation systems by applying social network analysis methods based on patent data. Our first impressions of the networks and its actors led our research towards investigating the role of public research. It became clear that two regions, Dresden and Jena, perform quite well with respect to innovative efficiency. The innovator networks in these two regions differ from the other two networks, Halle and Rostock, as they integrate a larger share of the innovating actors. They have also been able to increase this share over time and their networks show growing centralization. At the same time public research organizations seem to be especially prominent within these networks.

We then further investigated the role of public research as distinguished network actors to understand their special importance. The results strengthen two points i) universities and public research institutions are significantly more central, i.e., more interconnected within innovator networks than private actors; ii) there are differences between regions with respect to the centrality of public research. While in Dresden and Jena the institutions of public research seem to fulfil their function quite well, public research in Halle and Rostock seems less integrated.

Our research provides exemplary evidence that public research organizations which are well-connected within the local network of innovators are crucial for regional innovative performance. It is only through cooperating and interacting that their genuine occupation with generating new knowledge and collecting external knowledge becomes fruitful for the region. While the education of skilled labour is most important for the long-term increase in regional absorptive capacity, patent relations are much more a reflection of what is actually at the frontier of applied research. Well-connected public research actors within networks of patent innovators provide direct input of relevant knowledge for the regional economy.

A Actor Centrality

Table 8: Centrality ranks within 25 most active patentees in Dresden

			Personal relations		Cooperations		Scientist mobility		mean rank
	Patents	Public	C_D	C_B	C_D	C_B	C_D	C_B	(sort)
TU Dresden	231	1	1	1	2	2	1	1	1.3
Fraunhofer	278	1	2	2	1	1	2	2	1.7
IFW Institut fuer Festkoerper- und Werkstofforschung Dresden	68	1	4	3	4	3	5	3	3.7
Siemens AG	65	0	3	4	11	9	3	4	5.7
Forschungszentrum (FZ) Rossendorf	50	1	7	6	6	6	4	5	5.7
ILK Institut fuer Luft- und Kaeltetechnik gGmbH	98	1	6	9	5	5	5	9	6.5
HTW Dresden	18	1	5	5	3	4	14	13	7.3
Institut fuer Polymerforschung Dresden e.V.	27	1	8	8	7	8	9	11	8.5
Infineon AG	98	0	10	7	12	12	7	6	9.0
Robert Bosch GmbH	42	0	9	12	12	12	7	8	10.0
Feinchemie GmbH	16	0	10	11	7	10	12	10	10.0
Saechsisches Textilforschungsinstitut e.V.	21	0	13	10	18	12	10	7	11.7
VTD Vakuumtechnik Dresden GmbH	15	0	12	19	7	7	12	16	12.2
Koenig & Bauer AG	427	0	15	13	18	12	15	12	14.2
von Ardenne Anlagentechnik GmbH	36	0	15	16	12	12	15	15	14.2
BASF AG	28	0	13	15	18	12	10	17	14.2
Case Harvesting Systems GmbH	21	0	19	14	18	12	17	13	15.5
Meyer, Dirk	19	0	17	20	7	11	21	20	16.0
WHD Prftechnik GmbH	18	0	17	20	12	12	17	19	16.2
Fortschritt Erntemaschinen GmbH	19	0	19	17	18	12	17	18	16.8
Huels Silicone GmbH	58	0	21	17	12	12	21	20	17.2
ABB Patent GmbH	41	0	21	20	18	12	20	20	18.5
VEAG Vereinigte Energiewerke AG	21	0	23	20	12	12	25	20	18.7
Arzneimittelwerk Dresden GmbH	35	0	23	20	18	12	21	20	19.0
VEM-Elektroantriebe GmbH	19	0	23	20	18	12	21	20	19.0

Table 9: Centrality ranks within 26 most active patentees in Jena

			Personal relations		Cooperations		Scientist mobility		mean rank
	Patents	Public	C_D	C_B	C_D	C_B	C_D	C_B	(sort)
FSU Jena	115	1	1	1	4	5	1	1	2.2
IPHT Institut fuer Physikalische Hochtechnologie e.V.	72	1	2	3	3	3	4	4	3.2
Fraunhofer	79	1	3	5	2	1	5	5	3.5
Carl Zeiss Jena GmbH	222	0	4	4	5	4	3	3	3.8
JENOPTIK	107	0	6	2	7	7	2	2	4.3
Hans-Knoell-Institut	50	1	5	6	1	2	7	8	4.8
HITK Hermsdorfer Institut fuer Technische Keramik e.V.	26	1	7	7	6	6	6	6	6.3
TITK Thuer. Institut f. Textil- und Kunststoff-Forschung e.V.	63	1	8	8	8	8	10	11	8.8
Institut fuer molekulare Biotechnologie	11	1	9	9	9	11	8	9	9.2
TRIDELTA GmbH	9	0	10	11	14	11	9	7	10.3
SCHNEIDER Laser Technologies AG	39	0	10	15	9	9	10	13	11.0
Jenapharm GmbH	54	0	12	13	19	11	12	12	13.2
Aesculap Meditec GmbH	17	0	17	10	14	11	18	10	13.3
GESO GmbH	10	0	14	12	9	10	16	20	13.5
Max-Planck	9	1	13	16	14	11	13	16	13.8
Leica Microsystems GmbH	14	0	14	18	9	11	14	18	14.0
Siemens AG	17	0	16	14	19	11	14	17	15.2
Schott Glas AG	13	0	19	20	9	11	19	14	15.3
Textilforschungsinstitut Thueringen-Vogtland e.V.	14	1	19	17	14	11	19	19	16.5
Jenaer Glaswerk GmbH	9	0	21	19	19	11	19	15	17.3
inocermic GmbH	10	0	17	21	19	11	17	21	17.7
Plasttechnik Greiz GmbH	22	0	24	22	14	11	24	22	19.5
Agfa-Gevaert AG	11	0	22	22	19	11	22	22	19.7
Altenburger Industrienaehmaschinen GmbH	10	0	23	22	19	11	23	22	20.0
Ahlers, Horst	19	0	25	22	19	11	24	22	20.5
Geraer Maschinenbau GmbH	9	0	25	22	19	11	24	22	20.5

Table 10: Centrality ranks within 29 most active patentees in Halle

			Personal relations		Cooperations		Scientist mobility		mean rank
	Patents	Public	C_D	C_B	C_D	C_B	C_D	C_B	(sort)
Buna Sow Leuna GmbH	142	0	2	1	2	3	4	1	2.2
MLU Halle-Wittenberg	47	1	2	3	3	2	2	3	2.5
Leuna-Werke GmbH	37	0	1	2	6	6	1	2	3.0
Chemtec Leuna GmbH	14	0	7	6	4	4	6	6	5.5
FEW Chemicals GmbH	22	0	8	4	4	7	9	4	6.0
Haack, Eberhard	11	0	4	11	1	1	7	16	6.7
SynTec GmbH	9	0	8	5	11	10	7	5	7.7
Inofex GmbH	8	0	5	17	8	10	4	12	9.3
Deutsche Waggonbau AG Berlin	21	0	10	12	6	8	10	13	9.8
OvGU Magdeburg	10	1	14	9	8	5	16	9	10.2
KataLeuna GmbH	12	0	12	8	11	10	13	8	10.3
Maschinenfabrik Dornhan GmbH	9	0	5	17	19	10	2	11	10.7
Paraffinwerk Webau GmbH	36	0	12	7	19	10	10	7	10.8
Schweisstechnische Lehr- und Versuchsanstalt Halle GmbH	10	0	14	13	11	10	13	14	12.5
Rothe, Lutz	30	0	11	17	11	10	10	17	12.7
Krupp VDM GmbH	22	0	17	9	19	10	16	9	13.3
BASF AG	8	0	14	14	19	10	13	15	14.2
Air Liquide GmbH	11	0	17	15	8	9	19	18	14.3
Siemens AG	11	0	20	16	11	10	20	18	15.8
Slowik, Guenter	10	0	20	17	11	10	20	18	16.0
Kohlmann, Juergen	8	0	20	17	11	10	20	18	16.0
RMH Polymers	12	0	17	17	19	10	16	18	16.2
TU Dresden	9	1	23	17	11	10	26	18	17.5
Max-Planck	14	1	23	17	19	10	20	18	17.8
Romonta GmbH	10	0	23	17	19	10	20	18	17.8
ZEMAG GmbH	8	0	23	17	19	10	20	18	17.8
KSB AG	10	0	27	17	19	10	26	18	19.5
Deutsche Telekom AG	8	0	27	17	19	10	26	18	19.5
Omros GmbH	8	0	27	17	19	10	26	18	19.5

Table 11: Centrality ranks within 22 most active patentees in Rostock

			Personal relations		Cooperations		Scientist mobility		mean rank
	Patents	Public	C_D	C_B	C_D	C_B	C_D	C_B	(sort)
Uni Rostock	45	1	1	1	1	1	2	1	1.2
Privates Institut BioServ GmbH	8	0	2	3	6	5	1	4	3.5
BASF AG	6	0	6	2	6	5	5	2	4.3
Degussa-Huels AG	5	0	3	5	9	5	2	5	4.8
Institut fuer Organische Katalyseforschung an der Uni Rostock	10	1	4	6	4	4	4	9	5.2
Aventis GmbH & Co KG	10	0	8	4	9	5	5	3	5.7
Geier, Helrath	5	0	5	9	2	3	8	8	5.8
Energie-Umwelt-Beratung e.V.	14	0	6	7	6	5	5	7	6.0
BIOTRONIKGmbH & Co.	6	0	10	11	9	5	8	6	8.2
MaschinenBau und Umwelttechnik GmbH	5	0	10	8	9	5	8	10	8.3
Dudszus, Alfred	7	0	9	10	4	5	11	12	8.5
Stolz, Holger	7	0	10	11	3	2	16	13	9.2
GfE GmbH	6	0	13	11	9	5	11	11	10.0
Ingenieurtechnik und Maschinenbau GmbH	11	0	13	11	9	5	11	13	10.3
Gregor, Manfred Alexander	7	0	15	11	9	5	14	13	11.2
Anemometerbau GmbH	5	0	15	11	9	5	14	13	11.2
Noell-KRC GmbH	8	0	17	11	9	5	16	13	11.8
Dieselmotorenwerk Vulkan GmbH	7	0	17	11	9	5	16	13	11.8
Schnell, Ludwig	6	0	17	11	9	5	16	13	11.8
Buechler, Dirk	5	0	17	11	9	5	16	13	11.8
Kordelle, Rainer	5	0	17	11	9	5	16	13	11.8
Rossmann, Ulrich	4	0	17	11	9	5	16	13	11.8

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