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The influence of proximity dimensions on the edge betweenness centrality

in subsidized knowledge networks in Germany

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Abstract

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Germany

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State of the art
Network-theoretical concepts are increasingly applied in empirical studies. These studies provide evidence for firms'
positions in networks impacting their innovative performance (e.g. Powell et al., 1999; Boschma and Ter Wal, 2007).
This particularly concerns so-called gatekeeper organizations whose network embeddedness does not only impact their
own performance, but also the performance of adjacent organizations and in case of regional gatekeepers even the
performance of entire regional innovation systems (e.g. Graf, 2011; Giulani and Bell, 2005). From an empirical point of
view, these organizations can be identified using diverse measures of (network) centrality (Kauffeld-Monz and Fritsch,
2013).

Research Gap
While there exist a number of studies identifying organizations as being gatekeepers (cf. Graf, 2011; Morrison, 2008),
the question, which is so far widely ignored in the literature, is how organizations actually become gatekeeper? From a

network theoretical perspective, gatekeeper organizations are highly central in terms of betweenness centrality, i.e. the organization is characterized by being on a high number of the shortest paths in the network. However, we can rule out strategic positioning concerning this betweenness centrality and there are few theoretical concepts providing explanations for why organizations score high on this type of centrality.

Theoretical arguments

Scholars agree that networks are a suitable concept to map knowledge exchanges and flows (Ter Wal and Boschma, 2009; Ahuja, 2000). In this context, various studies highlight the need for a better understanding of the emergence and development of collaboration and the structure of knowledge networks (e.g., Glückler, 2007). In particular the proximity concept by Boschma (2005), which points out the relevance of various proximity dimensions for the formation of collaborations, has received considerable attention in the literature recently (e.g. Balland, 2012; Broekel and Boschma, 2011; Broekel and Hartog, 2013).

The theoretical framework of this paper combines the proximity and network theory. Moreover, the paper applies the concept of gatekeepers to achieve an in depth understanding of the structure of knowledge networks. Gatekeepers tend to connect different subgroups in a network. Consequently, one of the key arguments is that gatekeepers are characterized by having at least one gatekeeper link, i.e. a link with very high link-betweenness centrality. By moving away from the organizational level (node-level) to the link (dyad level), we can draw on the proximity concept providing explanations for the probability of such links being established and maintained. More precise, we aim at identifying the proximity configurations underlying gatekeeper links in order to learn more about how organizations become gatekeeper.

Method

By using a database on joint R&D projects funded by the German federal government, we are able to model a large number of inter-organizational R&D collaboration networks existing in different technologies for a number of years (cf. Broekel and Graf, 2012). For each of the network the most central, in terms of betweenness centrality, links are identified and their respective characteristics are compared to the average characteristics of links in these networks. The comparison involves multivariate regression analysis, which particularly aims at evaluating links' proximity configurations and the involvement of gatekeeper organizations.

First results

First preliminary results show that gatekeeper links are especially characterized by geographical and organizational proximity suggesting that gatekeeper organizations are likely to show superior capabilities in establishing links to organizations in geographic vicinity and to other sub-units or organizations, which belong to the their own mother organization.

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Proximities, edge betweenness centrality and the formation of gatekeepers: Evidence from subsidized knowledge networks in Germany

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1   Introduction

Network-theoretical concepts are increasingly applied in empirical studies. These studies provide evidence for firms' positions in networks impacting their innovative performance (e.g. Powell et al., 1996, 1999; Boschma and Ter Wal, 2007). This particularly concerns so-called gatekeeper organizations whose network embeddedness does not only impact their own performance, but also the performance of adjacent organizations and in case of regional gatekeepers even the performance of entire regional innovation systems (e.g. Graf, 2010; Giuliani and Bell, 2005; Giuliani, 2005). While there exist a number of studies identifying organizations as being gatekeepers (cf. Morrison, 2008; Kauffeld-Monz and Fritsch, 2013), the question, which is so far widely ignored in the literature, is how organizations actually become gatekeeper?

To answer this question, we combine the proximity and network theory. Moreover, the paper applies the concept of gatekeepers to achieve an in depth understanding of the structure of knowledge networks. Gatekeepers tend to connect different subgroups in a network. Consequently, one of the key arguments is that gatekeepers are characterized by having at least one gatekeeper link, i.e. a link with very high edge-betweenness centrality. By moving away from the organizational level (node-level) to the link level (dyad level), we can draw on the proximity concept providing explanations for the probability of such links being established and maintained. More precise, we aim at identifying the proximity configurations underlying gatekeeper links in order to learn more about how organizations become gatekeeper.

By using a database on joint R&D projects funded by the German federal government, we construct a large number of inter-organizational R&D collaboration networks existing

in different technologies for the period of 2003-2012 (e.g. Broekel and Graf, 2012). For each of the network the most central, in terms of betweenness centrality, links are identified and their respective characteristics are compared to the average characteristics of links in these networks. The comparison involves multivariate ordinary least-squares (OLS) regression analysis, which particularly aims at evaluating links' proximity configurations and the involvement of gatekeeper organizations. The second empirical model contains the investigation of the entire network across all technologies. We employ the multiple regression quadratic assignment procedure (MRQAP) (e.g Cantner and Graf, 2006; Broekel and Boschma, 2011a) to learn more about the direct impact of the respective proximity dimension on links' betweenness centrality.

The surprising results show that gatekeeper links are especially characterized by cognitive and social proximity suggesting that gatekeeper organizations are likely to show superior capabilities in establishing links to other cognitively or socially proximate gatekeepers in a respective technological field. Gatekeeper links within the whole network are featured by linking gatekeeper organizations, which belong to the same mother organization.

The paper is organized as follows. Section 2 provides the theoretical framework of this paper. Section 3 describes the database, which covers cooperative R&D subsidies used to construct knowledge networks. The empirical approach and the results are presented in Section 4. Section 5 summarizes critically the main findings and identifies future research.

2 Theoretical background

2.1 R&D-cooperations and subsidized knowledge networks

In order to obtain competitiveness, firms increasingly tend to collaborate with other organizations (Hagedoorn, 2002). This is especially true for knowledge-based economies. Accordingly, innovations occur mostly between universities, firms and research organizations rather than within them (Powell, 1990). In this context, different motives led organizations to collaborate in R&D. Firms participate in R&D alliances to minimize production costs, enhance productivity, and learn from each other (e.g. Hagedoorn, 1993; Aschhoff and Schmidt, 2008). In addition, inter-sectoral and inter-regional collaborations reduce the risk of lock-ins (Bathelt et al., 2004).

The evidence of the positive effects of R&D cooperations was taken into consideration by the European, national and regional policy. As a result the German government intensified the promotion of R&D-collaborations in the last twenty years. One third of today's subsidized R&D projects are collaborative projects, while the relative importance of individual R&D promotion decreases (Broekel and Graf, 2012).

Recent research evaluate the positive effects of R&D subsidies as well as subsidized joint R&D projects on firms' innovative performance. For example, Czarnitzki et al. (2007) examine simultaneously the influence of R&D subsidies and collaborations by using data of the Community Innovation Survey (CIS) from Finland and Germany. They point out that the positive impact of R&D subsidies on firms' patent activities can be increased by simultaneously cooperation. Barajas et al. (2011) prove the effects of subsidized international R&D collaborations by the European Union Framework Programme (FP) on firms' economic performance in Spain. They find empirical evidence for the positive influence of funded R&D joint projects on firms' technological capacities. However, most of these studies focus on the firm level. In contrast to this work, Fornahl et al.

(2011) analyse firm-level as well as regional-level effects of R&D subsidies on firms' patent activities in the German Biotechnology sector. Moreover, they also take the impact of network features and location on firms' innovative output into account. The main results indicate that the promotion of single R&D projects do not impact positively on firms' innovative output. On the other hand, subsidized joint R&D projects do so to a certain degree. In addition, Broekel (2013) examines the influence of R&D subsidies on the regional innovation efficiency by using a panel dataset for 270 German labour market regions. The empirical results confirm, among others, the negative effects of subsidized non-cooperative projects. Moreover, regions with poor innovative capacities especially benefit from collaboration among firms and funded inter-regional R&D linkages to public research institutes.

To summarize, subsidized joint R&D projects embed regions and organizations into inter-organizational knowledge networks. The determinants of the choice of collaboration partners will be discussed in the next subsection.

2.2 Tie formation and the proximity approach

Scholars agree that networks are a suitable concept to map knowledge exchanges and flows (Ter Wal and Boschma, 2008; Ahuja, 2000). In this context, various studies highlight the need for a better understanding of the emergence and development of collaboration and the structure of knowledge networks (e.g. Glückler, 2007; Boschma and Frenken, 2010; Cantner and Graf, 2006).

In particular the proximity concept by Boschma (2005), which points out the relevance of various proximity dimensions for the formation of collaborations, has received considerable attention in the literature recently (e.g. Balland, 2012; Broekel and Boschma, 2011a; Broekel and Hartog, 2013). The proximity approach is based on the French school of proximity dynamics (e.g. Torre and Rallet, 2005). Torre and Rallet (2005) distinguish between geographical and organized proximity. On doing so, they show that "[...] organized proximity offers powerful mechanisms of long-distance coordination that constitute the foundation of the increasing geographic development of socio-economic interactions" (Torre and Rallet, 2005, p.57). For a long time, geographical proximity has been seen as the main driver for knowledge exchange in the field of Economic Geography. Various empirical studies confirm the positive effects of geographical proximity on innovation (e.g. Jaffe, 1993; Feldman and Florida, 1994). However, Boschma (2005) argues that five different proximity types (cognitive, geographic, institutional, organizational, social) determine the creation of ties in knowledge networks. Consequently, actors are more likely to be connected when they are cognitively, geographically, institutionally, organizationally or socially proximate.

Approaches like regional innovation systems (e.g. Cooke et al., 1997) and industrial districts (e.g. Maskell and Malmberg, 1999) highlight the importance of geographical proximity for interactive learning and knowledge spillovers. Boschma (2005) defines geographic proximity as the physical or spatial distance between organizations. Short distances between agents enhance the exchange of tacit knowledge. Nevertheless he indicates "[...] that geographical proximity per se is neither a necessary nor a sufficient condition for learning to take place [...]" (Boschma, 2005, p.62). At least a certain level of cognitive proximity is necessary for knowledge transfer. In this context, geographical proximity has a growing impact on effective learning, if it is combined with other types of proximity (Boschma, 2005). Moreover, geographic proximity may be substituted by another type

of proximity. On the other hand, geographic proximity also acts as a substitute for other proximity dimensions (e.g. Singh, 2005; Ponds et al., 2007). However, Torre (2008, p.886) points out: "Face-to-face interactions are only required during certain stages of the innovative process [...]". Subsequently, temporary geographic proximity, for instance during meetings or conferences, would be sufficient for knowledge spillovers to take place.

Cognitive proximity defines the technological overlap between two partners. A sufficient absorptive capacity is crucial for identifying, interpreting and exploiting external knowledge (Cohen and Levinthal, 1990). Nooteboom et al. (2007) confirm empirically that too much cognitive proximity may be harmful to innovative performance. On the other hand, Boschma (2005) argues that excessive cognitive distance reduces the absorptive capacity of economic actors. Consequently, an appropriate cognitive distance enables effective knowledge transfer. In contrast to the other proximity types, cognitive proximity sets the framework for novel ideas. Hence, the effects of the other proximities on innovative performance have to be interpreted and empirically examined in concerning with cognitive proximity (Broekel and Boschma, 2011b).

Organizational proximity refers to the degree of autonomy and control which can be performed in organizational arrangements, either between organizations, or within organizations. A low level of organizational proximity implies especially informal relations between actors, while a higher level of organizational proximity can be defined as formal relationships, which are strongly based on control mechanisms. Subsequently, a lack of flexibility as well as a lack of control have negative effects on learning. An optimal level of organizational proximity may be characterized by loosely coupled systems (Boschma, 2005).

Institutional proximity defines the degree of similarity concerning formal rules and informal constraints (macro-level) shared by organizations (North, 1990). Thus, a certain level of institutional proximity provides a stable framework for interactive learning. On the other hand, too much institutional proximity increases the risk of institutional lock-in, because institutional rigidity leaves no room for innovations and new ideas (Boschma, 2005). Scholars use different approximations for institutional proximity. For instance, Ponds et al. (2007) measure institutional proximity by distinguishing among academia, government and industry. Broekel and Boschma (2011a) differentiate between non-profit and profit organizations.

Trust, friendship and experience based on repeated interactions are preconditions for socially embedded relations between actors. Such relationships increase the likelihood of R&D collaborations among partners (Boschma and Frenken, 2010). Consequently, social proximity refers to the degree of trust and loyalty between actors. Agrawal et al. (2006) confirm that firms are often tied, if their employees worked for their current partners' organization in the past. A high level of social proximity may have negative impact on interactive learning, if opportunistic behaviour is underestimated. At the same time, a high level of social distance negatively affects the innovation activities due to a lack of trust (Boschma, 2005).

In sum, common to each type of proximity is that too much proximity between actors on any of the dimensions have possibly negative impact on interactive learning. In this context, Boschma and Frenken (2010) introduce the so-called proximity paradox. Broekel and Boschma (2011a) empirically investigate the proximity paradox by using data of the Dutch aviation industry. They find empirical evidence for the existence of proximity paradox concerning cognitive and organizational proximity. Moreover, in accordance with Balland (2012) they confirm the simultaneous significance of all proximity types for the

formation of knowledge networks. However, Balland et al. (2012) prove that cognitive and geographical proximity become a greater importance as the industry matures. Broekel (2012) analyses how proximity configurations co-evolve when knowledge networks develop over time.

This brief review shows that tie formation and interactive learning in knowledge networks result through the interaction of all proximity types. In the next subsection, we focus on network theory to explain the characteristics and functions of gatekeepers in knowledge networks and identify a research gap.

2.3   Gatekeepers and gatekeeper links

The concept of national innovation systems highlights that successful innovation systems are based on effective linkages between public and private actors who exploit, generate and transfer new knowledge (e.g. Lundvall, 1992). However, localized knowledge spillovers (Feldman and Audretsch, 1996; Breschi and Lissoni, 2001) as a result of intensive, informal relationships in local innovator networks, popularized by the notion of local 'buzz' (Bathelt et al., 2004; Storper and Venables, 2004), emphasize the importance of geographical proximity for interactive learning and innovation. In this context, regional systems of innovation (Cooke et al., 1997) have received considerably attention in the literature (e.g. Asheim and Coenen, 2005; Asheim et al., 2011; Fritsch and Graf, 2011).

Nevertheless, dense local networks may involve the risk of regional lock-ins (Grabher, 1993). For instance, 'overembeddedness' (Uzzi, 1997) may lead to a lack of novel ideas. Thus, several scholars stress the importance for inter-regional ties to absorb external knowledge (e.g. Bathelt et al., 2004; Gertler, 1997). Consequently, to avoid lock-in situations and to benefit from the advantages of proximity at the same time, Bathelt et al. (2004) point out that innovation systems have to strengthen local as well as inter-regional knowledge flows.

In this context, Allen (1977) introduces the concept of 'technological gatekeepers'. He defines technological gatekeepers as R&D professionals with the ability to absorb external sources and to push the knowledge into their organizations. Building on this idea, Giuliani and Bell (2005), Morrison (2008) and Graf (2010), amongst others, employ the term 'gatekeeper'. According to their definition, gatekeepers are well connected to actors outside their local network and provide externally acquired knowledge to their local innovation system. Consequently, "[...] gatekeepers are of vital importance for sustained success of the respective system" (Graf, 2010, p.174). A number of studies investigate the functions and characteristics of gatekeepers. For instance, Giuliani and Bell (2005) confirm the importance of absorptive capacity for exploiting external knowledge by investigating a Chilean wine cluster. Morrison (2008) argues that a gatekeeepers' attitude is based on reciprocity with other actors of a cluster. By examining an Italian furniture district he proves that a number of leading firms have many ties to external actors but they are poorly connected to other local firms. These findings are confirmed by a study of an Italian wine cluster (Morrison and Rabellotti, 2009). However, Graf (2010) points out that the previous findings focus on case studies restricted to specific technologies. He analyses the networks of innovators in four East-German regions. The results indicate that public research organizations are more likely acting as gatekeepers than private large firms. Furthermore, absorptive capacity matters more than size in respect of being a gatekeeper. In addition, Graf and Krüger (2011) confirm empirically that innovation performance and the centrality of a gatekeeper are linked by an U-shaped relation. Moreover, gatekeeper

organizations are not able to exploit all advantages of their brokering position. These findings indicate that gatekeepers make some sort of public good available to their local system. According to the study of Graf (2010), the results prove that public research fulfils its mission to disseminate and share external knowledge regionally. In context with previous findings, Kauffeld-Monz and Fritsch (2013) find empirical evidence that universities and, to a smaller extent, large non-university research organizations fulfil the position of gatekeepers in eighteen East-German regional innovation networks. However, private firms are unrepresented in this respect. Kauffeld-Monz and Fritsch (2013) suggest that especially lagging regions benefit from the gatekeeper function of public research sector, because of its international relations and its public mission.

This brief review shows that the existing literature focus on the functions and characteristics of gatekeepers. However, it still remains unclear how organizations actually become gatekeeper. From a network theoretical perspective, gatekeeper organizations are highly central in terms of betweenness centrality, i.e. the organization is characterized by being on a high number of the shortest paths in the network (Freeman, 1977, 1979). Betweenness centrality for a node x is calculated by using the following formula:

$$b_x = \frac{\Sigma_{s<t} g_x^{(st)}/n_{st}}{\frac{1}{2}n(n-1)}$$

In this occasion, $g_x^{(st)}$ is the number of geodesic paths among the nodes s and t that pass through x. n_{st} is the total number of paths among the nodes s and t. Consequently, betweenness centrality is a measure which includes indirect ties within the network. In this way betweenness centrality defines an actor's ability to absorb knowledge that can be provided to network partners (Owen-Smith and Powell, 2004). As a result, organizations which score high on this type of centrality tend to connect different subgroups of a network and thus act as gatekeepers in innovation networks. By linking different subgroups of a network, we argue that gatekeepers are characterized by having at least on gatekeeper link, i.e. a link with a very high edge betweenness centrality (Edge betweenness centrality is calculated in the same way as node betweenness). We assume that this gatekeeper link tends to connect two sub-networks. The question therefore arises as to which factors lead to the formation of these sort of central research linkages and thus to the creation of gatekeeper organizations. To answer this question, we connect network theory and the proximity approach in the next subsection.

2.4 Hypotheses

As a result from the previous findings, gatekeeper organizations are characterized by a high level of absorptive capacity (e.g. Graf, 2010; Giuliani and Bell, 2005). Consequently, they are well connected with external knowledge sources as well as to local actors (e.g. Giuliani, 2005). Gatekeepers are able and have the willingness to share their acquired external knowledge with local partners (e.g Graf and Krüger, 2011; Kauffeld-Monz and Fritsch, 2013). In this way, gatekeepers help to increase the range of new ideas in a region (Wink, 2008). Private firms aren't always willing to share their knowledge within the local system (e.g. Morrison, 2008; Morrison et al., 2013). Thus, universities and, to a smaller extent, non-university research organizations fulfil the role of a gatekeeper more often than firms (e.g. Graf, 2010; Kauffeld-Monz and Fritsch, 2013).

In order to benefit from novel ideas, gatekeepers connect local actors to external knowledge sources (Bathelt et al., 2004). We assume that these external knowledge differs

significantly from the local knowledge base. This means that the established link between the gatekeeper organization and the external knowledge source shows a greater cognitive distance than the research links within the local system. According to the proximity approach (Boschma, 2005), we suppose that geographic proximity helps to overcome this cognitive distance and thus act as a substitute. This suggests the following two hypotheses.

Hypothesis 1. *Gatekeeper links in technology-specific knowledge networks are characterized by a higher cognitive distance than the average links.*

Hypothesis 2. *Gatekeeper links in technology-specific knowledge networks are characterized by a higher geographical proximity than the average links.*

The following section presents the subsidies data.

3   Data

We employ subsidies data on joint R&D projects funded by the German federal government. The largest share of these projects are managed by the Federal Ministry of Education and Research (BMBF). To a smaller extent, other ministries contribute as well. As mentioned in the previous section, policy especially aims at fostering collective learning processes in respect of promoting R&D collaborations. Empirical studies confirm the positive impact of this approach (e.g. Scherngell and Barber, 2009; Fornahl et al., 2011; Broekel, 2013). Consequently, subsidies data on joint R&D projects are a suitable tool for constructing innovation networks (Broekel and Graf, 2012). This database contains detailed information on more than 150,000 individual funds granted since 1960. The data is available via the 'Foerderkatalog' (www.foerderkatalog.de). Moreover, the data provides informations about the exact grant period, the name and postal code (location) of the receiving as well as executing organization, the granting sum, and the classification number. For instance, an university can be defined as the grant receiving organization, while a faculty or an institute are the executing actors. According to this, especially large organizations like multinational companies, large non-university research institutes (e.g. Max-Planck-Society) and universities contain different executing organizations. Constructed by the German Federal Ministry of Education and Research (BMBF), the classification number, called "Leistungsplansystematik", includes over 20 main classes. These main classes represent different technological areas, which cover energy research, biotechnology etc. In addition, the main classes are spitted into different sub-classes. The 6-digit classification number results from the highest level of disaggregation. For example, we can distinguish between bionic (L07534) or adaptronic (L07533). Moreover, non-technological activities are also existing within the research areas. For instance, perspectives for rural areas (DB0300) receive subsidies as well. A more detailed data description is carried out by Broekel and Graf (2012).

The empirical analysis is based on all subsidized joint R&D projects started between 2003 and 2012. Furthermore, this period contains 6,976 joint projects based on 27,831 individual funds. 7,413 (14,246) different receiving organizations (executing organizations) are involved (see Table 1). The name of the receiving organization in connection with the postal code of the executing unit is used to identify actors within the network. If two actors belong to the same joint project, a cooperation takes place. In this respect,

two-mode network data will be converted into a one-mode projection (Broekel, 2012). In order to construct a significant number of networks in different technologies, we employ 4-digit research area (see Broekel, 2012). Consequently we are able to construct 177 networks for the years 2003-2012. Networks with less than 10 links are excluded from the following investigation. In this way, there remain 146 networks (see Table 2).

Table 1. Subsidies data

	Count
Individual funds	27831
Receiving organizations	7413
Executing organizations	14246
Actors	8492
Joint projects	6976
4-digit research areas	177

Table 2. Network descriptives

n=146	Min	Max	Mean	SD
Nodes	5	1232	115.8	162
Links	10	5553	387.2	665.7
Density	0.007	1	0.17	0.22
Isolates	0	32	2.2	4.5
Share universities	0%	100%	31.7%	22%
Share firms	0%	88%	42.8%	26.4%
Share institutes	0%	85%	21.7%	12.6%
Share miscellaneous	0%	85%	3.8%	9%

4   Preliminary results

The first preliminary results show that gatekeeper links are especially characterized by cognitive and social proximity suggesting that gatekeeper organizations are likely to show superior capabilities in establishing links to other cognitively or socially proximate gatekeepers in a respective technological field (see Table 3).

Table 3. OLS regression results

	Model 1		Model 2		Model 3	
	Dependent variable: log(EDGEBETr)					
INTERCEPT	3.24***	4.68*	3.21***	3.85	3.76***	3.28
GEOPROXr	-	-0.02	-	-0.13	-	-0.10
COGPROXr	-	-0.20*	-	-0.33**	-	-0.24
SOCPROXr	-	-0.50**	-	-0.67***	-	-1.06
ORGPROXr	-	-2.53	-	-1.58	-	-1.25
INSTPROXr	-	0.13	-	0.13	-	0.19*
SIZE	-	0.001***	-	0.001***	-	0.001***
DENSITY	-	-2.3***	-	-2.16***	-	-2.22***
GATEKEEPER1	-2.42***	-	-2.35***	-	-3.12***	-
GATEKEEPER2	-0.68***	-	-0.63***	-	-0.67	-
No. of observations	146	146	146	146	146	146
Adj. R^2	0.73	0.44	0.65	0.45	0.65	0.43

* refers to a significance level of 0.1, ** to a significance of 0.05, and *** to 0.01.

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