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Be my (little) partner?!—Universities' role in regional innovation systems when large firms are rare

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Abstract

Structural differences regarding the presence of large firms are likely to influence the performance of Regional Innovation Systems. Regions lacking large firms to act as brokers of knowledge and coordinators of regional (R&D) collaboration may have to rely on other actors to form internal and external links. We investigate whether, in this case, universities can fulfill the needs of Small- and Medium-sized Enterprises (SMEs) with regard to coordination and knowledge flows. Using a data set of subsidized R&D collaborations, we compare universities' network positions in four model regions in Germany. Applying a Temporal Exponential Random Graph Model approach, we examine link formation and network structure with a focus on university–SME ties and their development over time. Results indicate that SMEs profit from connections to the university in all regions. Nevertheless, universities take more central roles in regions where the economic surrounding does contain fewer large firms as sources for knowledge exchange.

KEYWORDS

network structure, R&D subsidies, regional innovation system, SME, TERGM, university–industry collaboration

1 | INTRODUCTION

The success of a region in terms of innovation and economic growth is determined by the composition of its actors and their interplay. The literature on Regional Innovation Systems (RIS) has highlighted geographic proximity as a prerequisite for the building of trust and exchange of tacit knowledge through personal contact (Cooke, 1992; Cooke et al., 1997). An RIS is usually formed by actors from diverse stakeholder groups, such as local research institutions, firms, and governmental bodies. The innovative performance of RIS is determined by structural and procedural characteristics. Structural determinants include the composition of actors, the industries they are active in, the research institutions they can draw from and the challenges they have to face (Chatterton & Goddard, 2000; Czarnitzki & Hottenrott, 2009). Procedural elements encompass frequency of exchange and ability to coordinate collaborative activities (Giuliani & Bell, 2005). Empirical evidence emphasizes both elements to be important, because interactions between actors enable knowledge flows (Cantner et al., 2010), but relational configuration affects innovative performance as well (Graf & Henning, 2009).

With their unique ability to generate, absorb, and combine knowledge from different sources (Beise & Stahl, 1999; Petruzzelli, 2011) universities are a central building block of successful RIS. They provide access to academic knowledge, which positively impacts technological change, innovation, and growth, especially if the novelty of basic research can be combined with techniques and skills from the private sector (Agasisti et al., 2019; Lööf & Broström, 2008). Therefore, firms' abilities to form links with universities are probably crucial for innovative success of a region (Agrawal & Cockburn, 2003). Additionally, they provide links to actors outside the region, which are valuable sources of knowledge in their own right (Laursen & Salter, 2004).[1]

However, a prerequisite for successful collaboration is a sufficiently high absorptive capacity (Cohen & Levinthal, 1990) in the region. Large, multinational firms are of central importance in this regard, because they often conduct R&D on a sufficiently large scale themselves and may provide additional external contacts and access to resources needed to translate academic findings into marketable products. Furthermore, they possess the capabilities to organize and coordinate large-scale collaborative endeavors, both with industry and publicly funded research organizations (Huggins & Johnston, 2010). Therefore, they are natural partners for collaborations with academics, constitute a stabilizing force and connector and act as brokers of knowledge within RIS (Veugelers & Cassiman, 2005).

Distribution of large firms, however, is usually unequal within countries. Not all regions possessing a university are also home to large, multinational firms. Still, most of those regions have a significant number of Small- and Medium-sized Enterprises (SMEs). SMEs represent around 99% of companies in Europe and while innovative activity among them is highly skewed, their overall importance for economic growth and innovation has been emphasized by many scholars (see Laperche & Liu, 2013 for a review). To increase cohesion and reduce possible negative effects of regional disparities, a number of policies support R&D and university–SME collaboration to build functioning, sustainable RIS (Broekel, 2015). With SMEs having only limited resources and absorptive capacity, usually indicated by the absence of own R&D efforts (Moilanen et al., 2014; Muscio, 2007), universities' roles as coordinators of collaboration efforts, brokers of external knowledge (Tödtling & Trippl, 2005), and connectors of local actors may be more pronounced in these regions. This intuition is backed by empirical evidence demonstrating that SMEs need more assistance in innovative processes, especially when it comes to collaboration and the acquisition of funding (Collinson & Quinn, 2002; Czarnitzki & Hottenrott, 2011).

Focusing on four model regions in Germany, this paper contributes to the understanding of universities' roles in RIS by comparing their position in collaboration networks across regions with differing endowments of large firms and SMEs. We employ a combination of network parametrization and Temporal Exponential Random Graph Models (TERGMs) to answer the question whether universities fulfill additional roles in R&D collaborations if large firms are

[1]The special contribution of universities compared with other basic research institutions is their breadth of research fields together with public funding which ensures multidisciplinarity and autonomy (Charles, 2006).

fewer in numbers. Results suggest that universities do take central positions in all networks under investigation. However, their role as connectors and gatekeepers for SMEs is more salient in regions with fewer large firms.

This study proceeds as follows: In Section 2 we outline relevant literature for the conceptional framework followed by the development of formal hypotheses. Section 3 describes the regions under investigation and the overall empirical strategy. Data set and methods are outlined in Section 4. Section 5 presents results, whose implications are discussed in the concluding Section 6.

2 | CONCEPTUAL FRAMEWORK AND HYPOTHESES

RISs describe agglomerations of actors, their activities, and essential connections which can be characterized as a regionally embedded network structure. Networks facilitate direct knowledge exchange and organizational learning, creation, and enhancement of (regional) knowledge bases and draw actors from different backgrounds closer together (Broekel & Graf, 2012). They also foster access to knowledge sources from indirect ties (Burt, 1992; Granovetter, 1973) and enable knowledge flows from outside a region (Broekel et al., 2015; De Noni et al., 2018). Firms usually profit from networks as a source of information about technological trends and provision of support in difficult times (Freeman, 1982). Collaboration constitutes the basis for growth and evolution of the structure.

Universities often take central positions in knowledge networks (Graf & Henning, 2009; Kirkels & Duysters, 2010). As gatekeepers, they are deeply embedded in a region, but also have various links to the outside (Graf, 2010; Kauffeld-Monz & Fritsch, 2013). Therefore, they are important partners for firms (Veugelers & Cassiman, 2005), although institutional distance is not beneficial for collaboration in general (George et al., 2002; Lööf & Broström, 2008). Idiosyncrasies in routines and incentive mechanisms can be unfavorable in university–industry collaboration (Balland, 2012). Larger firms have an advantage over smaller ones in this regard, because size conditions resource availability: Large firms can strengthen absorptive capacity through inhouse R&D and simultaneously engage in collaboration to enhance their innovativeness (Nieto & Santamaria, 2010). They also approach all sorts of partners more easily (universities, small and large firms) because they can invest more time, financial resources, and human capital (Roesler & Broekel, 2017; Rogers, 2004; Smith et al., 1991).

There exist also innovative SMEs relying on external sources to compensate a lack of knowledge and capabilities to conduct extensive research (Beise & Stahl, 1999; Rammer et al., 2009). Still, SMEs are in many aspects poorly positioned for university–industry collaboration because of resource constraints (Buganza et al., 2014). However, successful establishment of collaboration may provide comparatively stronger benefits for SMEs through access to a very broad knowledge base (Acs et al., 1994) and additional sources of research-related funding (Mäkimatt et al., 2015).[2]

Several empirical studies also emphasize the relevance of policy support for SME–university collaboration. Tödtling and Kaufmann (2002), for example, show that government incentives for SMEs increase (regional) collaboration with universities and subsequently foster innovative output. Chai and Shih (2016) demonstrate that policy support is additive in SME–university collaboration, while it usually crowds out private investments in larger firms. Jung and Andrew (2014) highlight the importance of signaling with certified R&D facilities in SMEs helping to indicate competence and building absorptive capacity to partner up with universities. Muscio (2007) points out that collaboration itself as well as the sourcing of human capital from universities might be a suitable substitute for formal inhouse R&D efforts traditionally regarded as absorptive capacity enabling firms to pursue a more informal and/or open approach. Moilanen et al. (2014) seconds that especially non-R&D SMEs use collaboration and therefore external knowledge to enhance their innovative performance rather than absorptive capacity defined by inhouse R&D. Still, external sourcing for product innovation from universities might have negative consequences

[2]Even within the group of SMEs, it may be the larger ones that can muster the resources for collaboration with universities (Fontana et al., 2006).

for SMEs, such as longer project duration, higher cost, and lower competitive success of the resulting product (Kessler et al., 2000).

While universities may not be the ideal partner for SMEs, their ability to provide diverse knowledge bases and a widespread network of contacts may become crucial in regions, where the industrial landscape does not offer enough suitable (large) firms as collaboration partners (Fitjar & Rodríguez-Pose, 2020; Goldstein & Renault, 2004; Varga, 2000). Moreover, empirical evidence in network analysis has highlighted the tendency of new entrants to seek ties with central actors (Roesler & Broekel, 2017; Wanzenböck et al., 2014), which may mediate the relevance of geographical, cognitive, social, institutional, and organizational proximity (Boschma & Frenken, 2010) if universities are the most central actor in a network. On the contrary, universities are less crucial as a partner for SMEs when they take up a smaller share of overall innovative activity in a region (Drucker & Goldstein, 2007). Accordingly, we hypothesize:

H1: *Link formation between SMEs and universities is more likely in regions with fewer large firms.*

R&D projects should have a sufficient number of partners because the amount of devoted resources affects the outcome positively (Burt, 1992). However, project size and a multitude of partners increase demands on management capabilities and resources needed for coordination tasks (Schwartz et al., 2012), which reduces incentives to collaborate. Expectations of positive spillovers and public funding may (partially) mitigate these disincentives to R&D collaboration (Czarnitzki et al., 2007). Besides the number of partners, the variety of links gained from network involvement is also of relevance. Being involved in projects with several partners bears the potential to benefit from indirect ties (Ahuja, 2000; Granovetter, 1973), for example, to funding institutions and other firms (George et al., 2002). Moreover, regional diversity should increase with multiple partners granting access to more distant knowledge bases (Grillitsch et al., 2015). Independent of the available number of larger firms, universities are likely to constitute important local actors, who also maintain ties within and beyond a region. SMEs should profit more if they are directly linked to the local university because the number of available indirect ties to further organizations inside and outside the region is vastly increased (Huggins & Prokop, 2017). Accordingly:

H2: *SMEs linked to the university have more indirect ties throughout the network than SMEs not linked to the university.*

Having an advanced knowledge base does not only make collaboration possible and influences its success, it might also affect the frequency of collaboration (Bishop et al., 2011). This is true not only for the collaboration between firms but also for university–firm interaction (George et al., 2002; Giuliani & Bell, 2005). Universities as collaboration partners have complex demands and the learning effect from university–industry collaboration should be beneficial for engagement of SMEs with partners in the future. This includes organizational learning in terms of initiation and management of collaboration, which is helpful for future engagements with the same or other organizations (George et al., 2002).[3] Additionally, membership in a network increases the probability of further collaboration for the respective actor (D'Este & Perkmann, 2011). At the same time, SMEs have to consider the risk of less control on knowledge flows which occur when too many ties exist (Autant-Bernard et al., 2007). Especially horizontal networks with firm partners bear the risk of opportunistic behavior (Gulati & Singh, 1998). Additionally, transaction costs for coordinating multiple collaboration partners and collaboration projects might exceed its benefits (Mishra et al., 2015). Nevertheless, evidence shows that especially SMEs profit from simultaneous collaboration projects (Hottenrott & Lopes-Bento, 2016).

[3]This follows the idea of "triadic closure" that unconnected partners of the same organization are likely to become connected directly as well (Broekel & Hartog, 2013).

As SMEs are restricted in resources such as financial and human capital they need to act strategically to benefit from any kind of investments. Special attention should therefore be given to collaboration breadth and depth directly affecting collaboration cost and outcome (Laursen & Salter, 2004). Investment in a collaboration between university and SME seems to be rather high considering the organizational distance. However, once an SME has collaborated with a university, the experience probably facilitates further collaboration.

We therefore postulate:

H3: *SME–university linkages increase the likelihood to establish collaboration with regional universities repeatedly.*

3 | SELECTION OF REGIONS AND EMPIRICAL STRATEGY

We compare four different German regions, who all exhibit pronounced research capabilities as a necessary condition for successful RIS. These are Aachen, Brunswick, Dresden, and Karlsruhe. They were chosen, because they all encompass the main city of comparable size, host one major university, belonging to the TU9 consortium (Stump, 2018) and contain further publicly funded research institutions (Leibniz and Helmholtz associations, Max-Planck society[4]). Figure 1 shows the location of the units of analysis in different parts of Germany to account for regional idiosyncrasies.

Aachen is located in the very west of Germany, in North-Rhine Westphalia close to the Dutch and the Belgian borders. It is home to the Rheinisch-Westfaelische-Hochschule-Aachen (RWTH), the largest technical university in Germany. The city of Brunswick lies towards the geographical center of Germany in the federal state of Lower Saxony. The biggest scientific institution is the Technical University Carolo-Wilhelmina Brunswick (TU Brunswick). Dresden is the capital of the federal state of Saxony and is situated in the very east of Germany. It is host to the Technical University Dresden (TU Dresden). The city of Karlsruhe is located in the southwest of Germany in the federal state of Baden-Württemberg. The Karlsruhe Institute of Technology (KIT) unites the former technical university and a research center of the Helmholtz association. Three of the regions are geographically close to major economic agglomerations. Only Dresden is somewhat isolated. Despite significant economic activity within the cities wider surroundings (industry clusters, such as Silicon Saxony, Biosaxony, and SenSa), there is a lack of large (multinational) corporation headquarters (Haseloff et al., 2015) and the capacities for corporate R&D that often accompany them.

The most important feature of our analysis is the different compositions with regard to SMEs and larger companies in the region (see Table 1). As the unit of analysis, we chose the administrative district, because sizes are conducive for a comparison based on the number of large companies in a region. The large-firm concentration, measured as a number of large firms to a total number of firms, ranges from 0.37% (Dresden) to 0.46% (Brunswick and Karlsruhe), which highlights the overall importance of SMEs in Germany. It also illustrates that a comparison according to relative numbers is less sound. However, when looking at the total number of large firms pronounced differences emerge. The regions of Dresden and Brunswick show substantially fewer large firms compared with Aachen and Karlsruhe.

For this study a network analysis of publicly funded research consortia is chosen as an exploratory approach to exploit the relational data given in the research consortia. Furthermore, we employ the TERGMs methodology outlined in Leifeld et al. (2018) to analyze factors influencing link creation. Originating from the Exponential Random Graph Model (ERGM; Hanneke et al., 2010) considering networks as single

[4]Besides publicly financed universities, research institutes belonging to the research associations of the Leibniz, Helmholtz, or Max-Planck Society state the second pillar of basic research in Germany. The single institutes have a strong focus on specific scientific fields complementing university research and building additional bridges towards applied research and industry (Deutscher Akademischer Austauschdienst [DAAD], 2017).

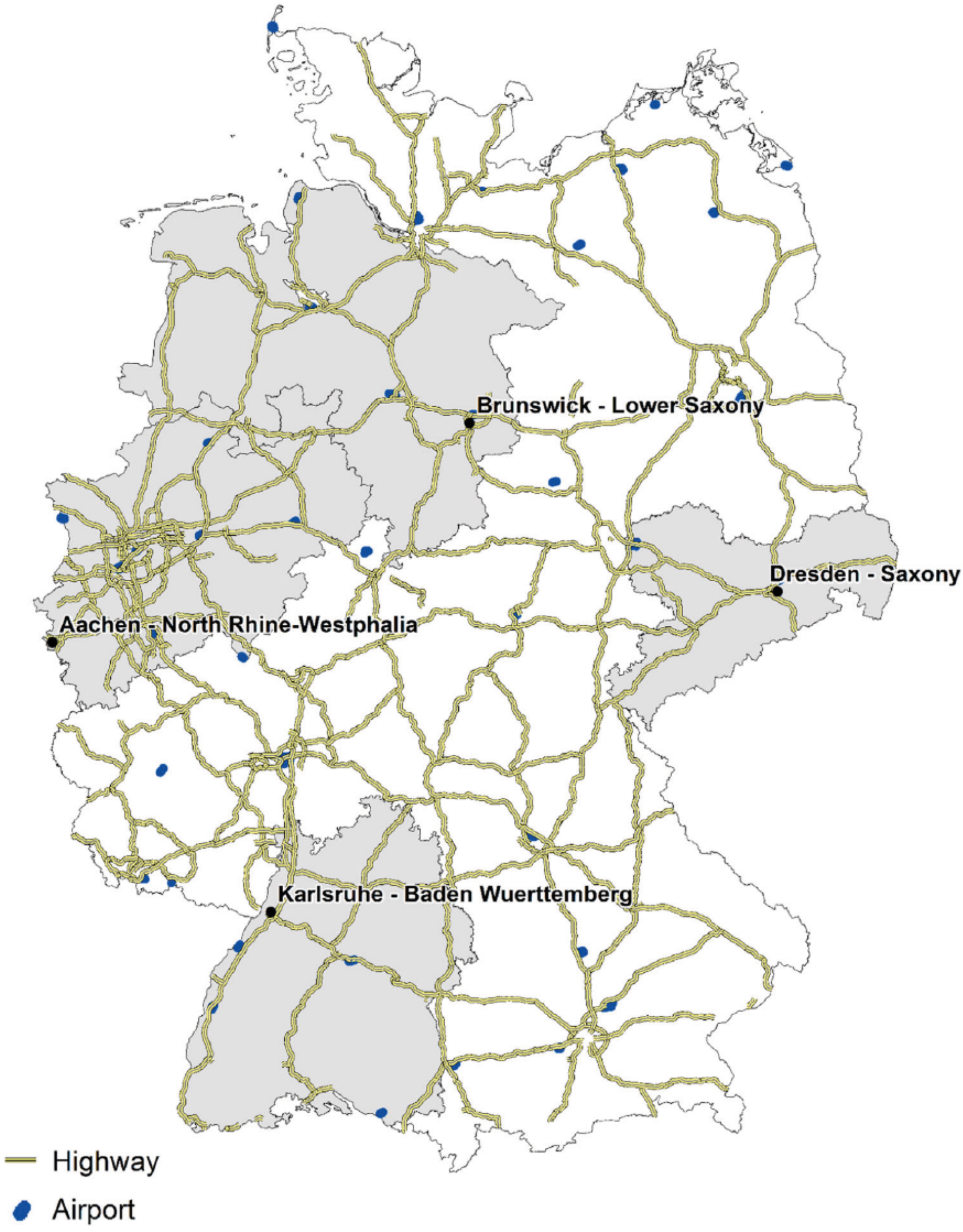

FIGURE 1 Map of Germany with the focal cities (black) and federal states (gray).

multivariate observations, where link creation depends on exogenous data treated as covariates, TERGM considers intertemporal dependence of several consecutive network observations and aims to identify previous network structures that determine current network realizations (Leifeld et al., 2018). The family of ERGM Models is considered a suitable statistical approach to investigate the evolution, dissolution, and structural analysis of networks (see Brennecke & Rank, 2017; Broekel & Bednarz, 2019; Broekel et al., 2014). The baseline model was estimated using the statistical software R and the package btergm (Leifeld et al.,

TABLE 1 University, city, and regional characteristics.

	Aachen	Brunswick	Dresden	Karlsruhe
No. of students at focal university	45,000	20,000	33,000	25,000
City population	557,026	249,406	556,780	312,060
Population per km^2	788	1294	1695	1799
No. of large firms[a]	865	223	239	544
Share of large firms in %[a]	0.444	0.461	0.374	0.459

[a]Number has drawn from the German company register for NUTS2 regions for the year 2017.

2018). Separate models were estimated for the four regions. The model specification uses a bootstrapping approach running 1000 replications each.

4 | DATA AND VARIABLES

4.1 | Data

We use subsidized R&D collaborations through national funding programs from the "Foerderkatalog" of the German Government as data source (Fornahl et al., 2011; see Autant-Bernard et al., 2007 for a similar approach on the EU level) as opposed to studies focusing on patent data (Cantner et al., 2010; Graf & Henning, 2009; Schilling & Phelps, 2007; Ter Wal & Boschma, 2009) neglecting SMEs or survey data underreporting links. The database is available online and combines information on subsidized R&D projects from several German Ministries. Most importantly, the data allow for the distinction of single and collaborative grants and also the type of recipient. The funding requires the partners to agree on some core rules which ensure knowledge transfer between partners and set incentives for innovative output (see Broekel & Graf, 2012 for details). While the funding schemes cover full research expenses of universities and other research institutes, firms only get shares of research expenses funded. Nevertheless, both types of recipients are eligible for funding and some schemes even request consortia to consist of specific types of partners such as universities, private firms, and sometimes SMEs in particular. Private firms as well as universities may apply for funding without limits on the number of consecutive or concurrent projects. Our analysis makes no restriction on the type of funding scheme.

The analyses cover the time span from 2006 to 2017 during which any collaborative project with at least one partner originating in the four model regions is included in the sample.[5] The collaboration between any two partners constitutes the links for our network analysis. The minimum size of the consortia therefore is two, the largest project includes 50 project partners. The mean project size is 5.6. The projects last from 2 months up to 146 months. The mean duration is 38 months. We construct ego networks on the city level as the core of the model regions. The project partner entities (node) in our network can belong to one of the following types: (focal) university, large firm, SME, other research organizations, and miscellaneous. SME classification is based on the number of employees with a cut-off at 250 (Schmiemann, 2008), which is determined through the Bureau-van-Dijk database Amadeus (van Dijk, 2010). For the TERGM we construct one network realization per year accounting to 12 network observations which include projects spanning over more than one observation period. A project lasting

[5]Partners are listed as "receiving" and "executing" unit. For the following analyses we focus on the geographical location of the executing unit. Universities are collapsed into one entity, because different units are usually located in one place.

for 3 years would therefore appear as link between two actors in at least three network observations in our data set.

4.2 | Variables

The variables are calculated for all nodes but refer to different aspects of the network the node is located in. While node-level variables describe the characteristics of the node itself. Network-level variables supplement information about the whole network of the node(s) in question.

At the node level (organization), we differentiate firms from research institutes, universities, governmental bodies, or nonprofit organizations and associations (*private sector*). This variable takes the value "1" for (privately owned) firms and "0" otherwise. Within the firm group, we delineate SMEs from larger firms (SME). We also include *betweenness centrality* at the node level to consider a position in the network and relevance in terms of bridging unconnected nodes:

$$C_B(i) = \sum_{j \neq i \neq k} \frac{g_{jk}(i)}{g_{jk}}, \tag{1}$$

where g_{jk} is the number of shortest paths between two nodes j and k, and $g_{jk}(i)$ is the number of paths that contain actor i.

In the descriptive network characteristics, we also include normalized *degree centrality* representing the number of links a node actually has divided by the possible number of links of this node:

$$C_D(i) = \frac{d_i}{(g - 1)}, \tag{2}$$

where the number of ties of an actor d_i divided by the number of possible ties (Graf & Henning, 2009).

Concerning the geographical proximity of any node with the focal city and, hence, the focal university, we include two dummy variables denoting nodes inside the focal city region (*city*) and inside the federal state (*state*). The former signifies very close proximity associated with certain benefits, among others, lower barriers to start collaboration (Cooke et al., 1997). The latter indicates medium proximity and captures possible effects from belonging to the same federal state administration and a larger economic surrounding. The variables have been reverse-coded and relabeled to *outside city* and *outside state* in Table 2 (TERGM models) to allow for a more direct interpretation accordingly.

In addition to the position of a node, existing embeddedness in networks may drive the likelihood to form new links. Accounting for different geographical levels and existing collaborations at the same time, we include three *strength* variables summing up existing links on the respective regional level (weighted to account for the possibility of the existence of more than one edge between two nodes). *Strength within city* counts the number of links within the city level, *strength within state* on the federal state level and *strength whole network* on the country level (all of Germany). The latter represents the overall network embeddedness of any node at a given time. *Strength within city* and *strength within state* are set to "0" by default if a node is not located within the corresponding geographical boundary. Therefore, these variables represent a possible regional strength (or a "bias") in the network of a focal node, conditional on being located in medium or very close proximity to the focal city.

Table 3 summarizes descriptive statistics for these variables grouped by model regions. Table 4 highlights important structural characteristics of the four different networks.

TABLE 2 TERGM estimation results.

Variables	Aachen coefficient (confidence intervals)		Brunswick coefficient (confidence intervals)		Dresden coefficient (confidence intervals)		Karlsruhe coefficient (confidence intervals)	
Private sector	0.080*		0.079		0.247*		0.117	
	(0.048	0.135)	(−0.017	0.183)	(0.113	0.358)	(−0.060	0.327)
SME	−0.006		0.011		−0.014		−0.127*	
	(−0.099	0.089)	(−0.094	0.108)	(−0.084	0.048)	(−0.264	−0.004)
Betweenness centrality	−0.000*		−0.000		−0.000*		−0.000*	
	(−0.000	−0.000)	(−0.000	0.000)	(0.000	0.000)	(−0.000	0.000)
Outside city	0.040		−0.219*		−0.245*		−0.148*	
	(−0.140	0.148)	(−0.410	−0.065)	(−0.349	−0.133)	(−0.269	−0.004)
Outside state	0.195*		0.063		0.095		0.117*	
	(0.049	0.319)	(−0.022	0.162)	(−0.015	0.206)	(0.044	0.166)
Strength within city	0.056*		−0.031		−0.135*		0.007	
	(0.011	0.082)	(−0.170	0.020)	(−0.1810	−0.0778)	(−0.025	0.041)
Strength within state	0.000		−0.004		0.023*		0.001	
	(−0.007	0.009)	(−0.012	0.004)	(0.003	0.040)	(−0.011	0.009)
Strength whole network	0.017*		0.017*		0.023*		0.013*	
	(0.009	0.022)	(0.010	0.021)	(0.0140	0.027)	(0.012	0.015)
Memory	−6.599*		−5.891*		−6.359*		−5.982*	
	(−7.098	−6.271)	(−6.382	−5.544)	(−6.767	−6.052)	(−6.391	−5.689)
Edges	−1.374*		−1.298*		−1.085*		−1.722*	
	(−1.814	−0.596)	(−2.063	−0.328)	(−1.667	−0.555)	(−2.240	−1.116)
gwesp fixed	2.803*		2.758*		2.791*		3.245*	
	(2.699	2.938)	(2.670	2.898)	(2.675	2.995)	(3.026	3.489)
gwdegree	−6.902*		−5.293*		−5.568*		−6.954*	
	(−7.898	−6.190)	(−5.659	−4.965)	(−6.054	−5.161)	(−7.447	−6.351)

Abbreviations: SME, Small- and Medium-sized Enterprise; TERGM, Temporal Exponential Random Graph Model.
*Statistically significant at the 5% level.

The TERGM creates further variables on the network level. Because they are not an input of our analysis they are not included in the descriptive statistics, but discussed in Section 5. First, a factor that captures previous collaborative activities (an edge between two specific nodes) up to two periods in the past (*memory*) is included. Although we cannot directly account for multiple collaborations at the same time beyond the "weighing" addressed in the *strength* variables above due to technical limitations, previous experience with a partner may affect the future likelihood of collaboration or at least have some "cooldown." Additionally, the

TABLE 3 Descriptives.

	N	Time periods	Mean	SD	Median	Min	Max
Aachen							
Private sector	23,450	14	0.782	0.413	1	0	1
SME	23,450	14	0.487	0.500	0	0	1
Betweenness centrality	23,450	14	186.951	3,407.370	0	0	25,1051.7
City	23,450	14	0.921	0.269	1	0	1
State	23,450	14	0.697	0.459	1	0	1
Strength within city	23,450	14	0.059	0.937	0	0	47
Strength within state	23,450	14	0.494	457.082	0	0	258
Strength whole network	23,450	14	526.302	202.454	0	0	972
Brunswick							
Private sector	19,642	14	0.741	0.438	1	0	1
SME	19,642	14	0.478	0.500	0	0	1
Betweenness centrality	19,642	14	188.029	2,194.030	0	0	13,5665.0
City	19,642	14	0.9434	0.231	1	0	1
State	19,642	14	0.844	0.363	1	0	1
Strength within city	19,642	14	0.039	0.673	0	0	34
Strength within state	19,642	14	0.330	302.401	0	0	139
Strength whole network	19,642	14	544.476	192.487	0	0	779
Dresden							
Private sector	22,876	14	0.749	0.434	1	0	1
SME	22,876	14	0.492	0.500	0	0	1
Betweenness centrality	22,876	14	215.283	2,942.650	0	0	187,298.0
City	22,876	14	0.887	0.316	1	0	1
State	22,876	14	0.763	0.425	1	0	1
Strength within city	22,876	14	0.090	121.633	0	0	65
Strength within state	22,876	14	0.334	260.198	0	0	123
Strength whole network	22,876	14	400.516	139.735	0	0	563
Karlsruhe							
Private sector	30,506	14	0.788	0.409	1	0	1
SME	30,506	14	0.474	0.499	0	0	1
Betweenness centrality	30,506	14	297.648	3,735.290	0	0	243,139.2
City	30,506	14	0.925	0.264	1	0	1
State	30,506	14	0.696	0.460	1	0	1
Strength within city	30,506	14	0.058	0.894	0	0	42

(Continues)

TABLE 3 (Continued)

	N	Time periods	Mean	SD	Median	Min	Max
Strength within state	30,506	14	0.663	538.818	0	0	285
Strength whole network	30,506	14	572.786	213.915	0	0	979

Abbreviation: SME, Small- and Medium-sized Enterprise.

TABLE 4 Network characteristics for the four model regions (degree, degree centrality, and betweenness centrality for the focal university).

Region	Level	No. of nodes	No. of SMEs	Degree	Degree centrality	Betweenness centrality
Aachen	Germany	1,675	817	1,529	0.529	0.394
	Federal state	506	289	495	0.551	0.471
	University–SME	290	289	179	0.502	0.373
	City	134	98	114	0.481	0.288
	University–SME	99	98	53	0.418	0.179
Brunswick	Germany	1,403	670	1,432	0.451	0.243
	Federal state	221	126	276	0.491	0.357
	University–SME	127	126	87	0.460	0.254
	City	80	55	81	0.481	0.264
	University–SME	56	55	53	0.527	0.314
Dresden	Germany	1,633	803	1,220	0.397	0.308
	Federal state	387	255	299	0.469	0.423
	University–SME	256	255	160	0.471	0.396
	City	184	116	154	0.508	0.351
	University–SME	117	116	78	0.491	0.253
Karlsruhe	Germany	2,179	1032	1,989	0.417	0.226
	Federal state	664	332	677	0.440	0.308
	University–SME	333	332	199	0.437	0.273
	City	164	90	106	0.270	0.115
	University–SME	91	90	37	0.256	0.083

Abbreviation: SME, Small- and Medium-sized Enterprise.

variable *gwesp fixed* considers triadic closure, a process where two unconnected nodes form a link when they have a common connection to a third node (Hunter, 2007). This variable is calculated as the geometrically weighted edgewise shared partner (hence the abbreviation "gwesp"). Lastly, to control for a possible Matthew effect—the phenomenon that nodes with many ties also tend to be more likely to form new ties (see Merton, 1968)—the variable (*gwdegree*) is included. It is a geometrically weighted degree statistic that measures the inverse of preferential attachment (Ferligoj et al., 2015).

5 | RESULTS

5.1 | Descriptive results and network visualizations

The network overview in Table 4 above already yields some insights into the connectedness and centrality of universities and SMEs. SMEs account for roughly half the nodes across all regions. On the level of the federal states, the networks differ somewhat in connectedness on the regional level. For Dresden it is noteworthy that the region exhibits the highest number of funded firms in the focal region but ranks only third in the number of overall actors on a German-wide basis. Degree centrality on the city level is lowest for Karlsruhe, which is in line with our reasoning, because the region also exhibits the lowest number of SMEs in funded projects. Unsurprisingly, betweenness centrality is also low for Karlsruhe, but more or less similar for Dresden and Aachen. This may reflect a similar number of ties generated on the national level (albeit with a different number of actors in the focal region). The following descriptions focus on the network of collaborative R&D projects on the level of the federal states. This level is chosen because a too-narrow focus on the city as the core of the RIS may neglect actors that are geographically close to the universities but not located within the administrative boundaries of the “cities.”

Table 5 focuses on the node level and differentiates SMEs located in the federal state that shares a link with the focal university from those that do not.

Mean degree is smaller for SMEs not linked to the university compared with those which are linked to the university (Mann–Whitney *U* test significant at the 1% level).

The graphs in Figure 2 show project partners (nodes) and collaboration activities (edges) up to the level of federal states. Thicker edges represent higher frequencies of collaboration (in different projects). Isolated nodes stem from actors in the model region having connections only beyond the federal state level (within the rest of Germany). Green nodes are SMEs with a university link, red nodes are SMEs within the focal region without a connection to the university (therefore, green nodes cannot be isolated by definition). Actors with a high betweenness centrality are depicted in yellow. The star-shaped node indicates the most central actor which is the focal university in all four model regions. The second most central actor is usually another university in the network within the federal state or a research organization.

When comparing the networks of Dresden (lower right quadrant) and Aachen (upper right quadrant), Dresden seems to have less isolated nodes (especially SMEs depicted in red), despite having more actors in the region (city level, see Table 4). Together with a high betweenness centrality of the university in Dresden (Table 4) this is a first hint corroborating our propositions that universities act as brokers and coordinators in regions with fewer large firms. In comparison to Dresden, regional SMEs in Aachen seem to be more adept in maintaining links to outside the federal state without the help of a central university actor.

TABLE 5 Differences in the distribution of degree centrality between SMEs with and without a link to the local university.

Region	SMEs with university link	SME's mean degree	SMEs without university link	SME's mean degree	Mann–Whitney *U* test (W)
Aachen	145	9.455	144	5.271	7297.500*
Brunswick	58	10.862	68	5.221	1374.000*
Dresden	120	7.458	135	5.363	5929.000*
Karlsruhe	145	11.745	187	4.882	7297.500*

Abbreviation: SME, Small- and Medium-sized Enterprise.

*Statistically significant at the 5% level.

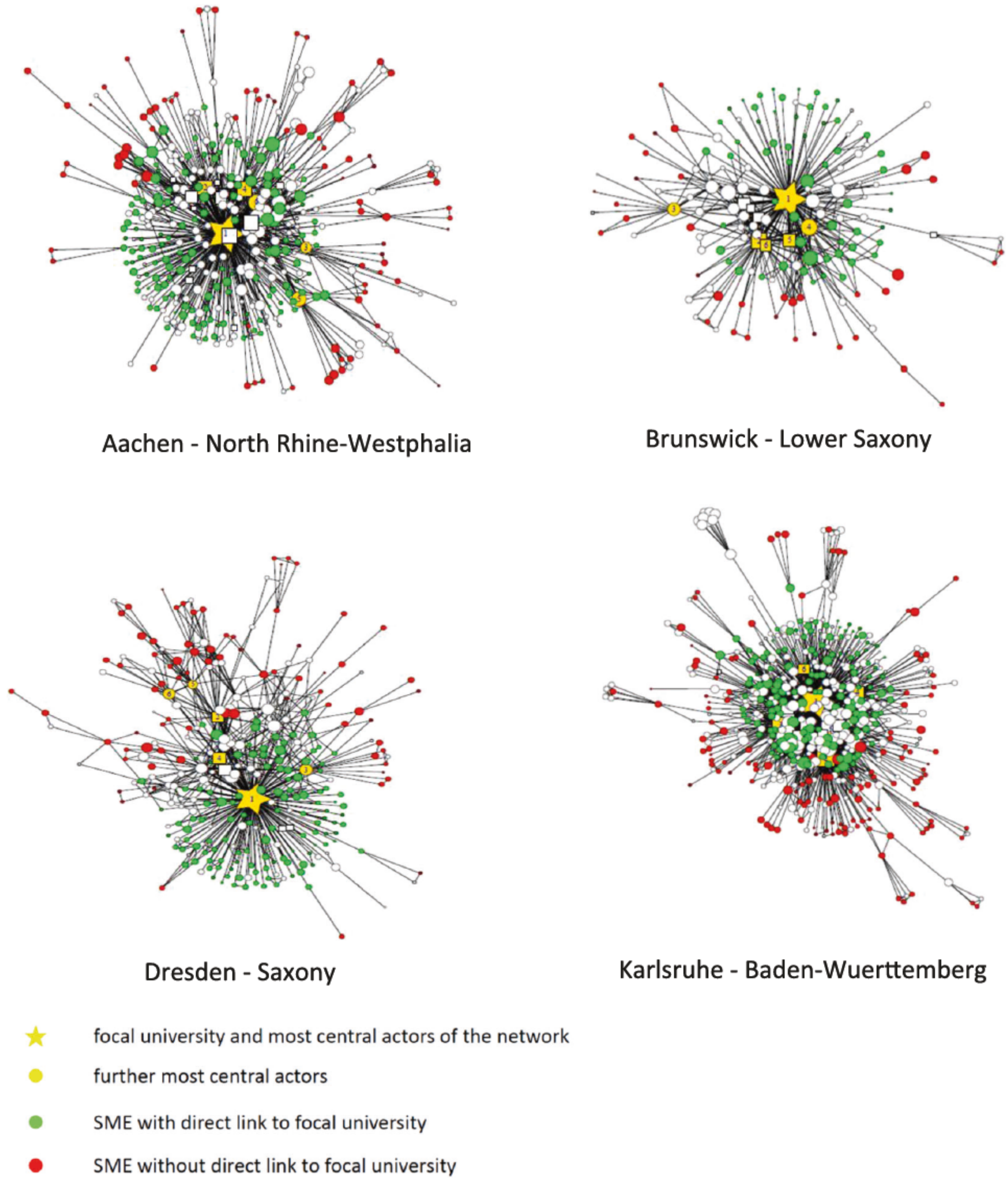

FIGURE 2 Network depictions. SME, Small- and Medium-sized Enterprise.

5.2 | TERGM results

Node-level coefficients in the TERGM analyses reveal that belonging to the *private sector* raises the probability to collaborate as opposed to research institutes (Table 2). A likely explanation lies in our data source: overall more private firms are included in the data set because certain governmental funding schemes are targeted at increasing research and development in the private sector in general and a fostering of

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university–industry relations in particular. The effects are positive in all regions but only statistically significant in the networks of Aachen and Dresden. The coefficient for *SME* is only significant in the network of Karlsruhe and shows a small negative effect. Corroborating prior evidence, SMEs in our sample seem to be less prone to initiate new collaborations compared with larger firms. *Betweenness centrality* is significant in all networks but the one of Brunswick.

Concerning the location of the node, *outside city* is significant and negative for all networks but Aachen. New link formation is less likely if a node is not located within the focal city. The results are in line with the literature on the facilitation of collaborative activities through geographical proximity (Mukherji & Silberman, 2013). *Outside state* is significant and positive for the networks of Aachen and Karlsruhe. For Karlsruhe the combination of a negative effect for *outside city* and a positive effect for *outside state* hints at an inverse U-shape: close proximity is an asset for collaboration and intermediate proximity within a federal state might not be sufficient to bridge gaps in cognitive or organizational differences (link formation outside the city is less likely). However, collaboration over larger distances allows for a broader set of possible collaboration partners with better fits in terms of cognitive and organizational proximity (Tödtling & Grillitsch, 2014). Increased likelihood for link formation outside the federal state may also reflect a more active search behavior for partners complementing a node's skills and assets (Autant-Bernard & LeSage, 2011; Fitjar & Rodríguez-Pose, 2020).

Strength within city has a statistically significant coefficient for Aachen, which indicates that the more embedded nodes in the focal city have a significantly higher likelihood to form new links. Dresden gives us especially interesting results. We find a statistically significant negative coefficient (*strength within city*) suggesting a lower likelihood to form new collaborations for actors that are already embedded in the focal city. Simultaneously, *outside city* is also statistically significant with a negative sign indicating that forming new links is less likely for nodes outside the focal city. This suggests that regional proximity is especially important in Dresden, but there may be lock-in effects. Another possibility is a limited availability of suitable partners within the city itself, which gets "exhausted" as the density of the network increases.

The lagged term accounting for previous collaborations (*memory*) shows a strong negative effect for all networks indicating that prior collaborations have a negative effect on the creation of new links. A possible explanation could be that subsidized projects are used as a first formal collaboration which results in subsequent more informal projects or projects financed by the firms themselves (Aerts & Schmidt, 2008). This would meet the funding goals to fuel collaborative activities and provide a first incentive to a large number of single actors (Broekel, 2015). Alternatively, the timeframe of our analysis might not take the following collaborations into account since the time for initiating and formally applying for a new project might be longer than we can account for. On the structural level of the network the variable controlling for triadic closure (*gwesp fixed*) reveals a tendency to include new partners into the network that is shared between existing nodes and is significant and positive for all regional networks. Lastly, the significant negative effect for *gwdegree* indicates preferential attachment supporting a Matthew effect. With the university having more links, SMEs connected to the university also gain more indirect links supporting H2.

We compare the distribution of edgewise shared partners, geodesic distances (between pairs of nodes) as well as the degree distribution to assess the goodness of fit of the TERGM models (Figure A1) as proposed by Hunter et al. (2008). These were calculated using 200 simulations per time step, adding up to 2400 simulations per region to be compared with the observed networks. While geodesic distances and degree distribution show satisfactory fits of simulated and observed networks for all four regions, there is some deviation between simulation and observation with regard to edgewise shared partners. However, because the reason is mainly a difference in the prediction of lower numbers of edgewise shared partners, we conclude that the models are of acceptable quality.

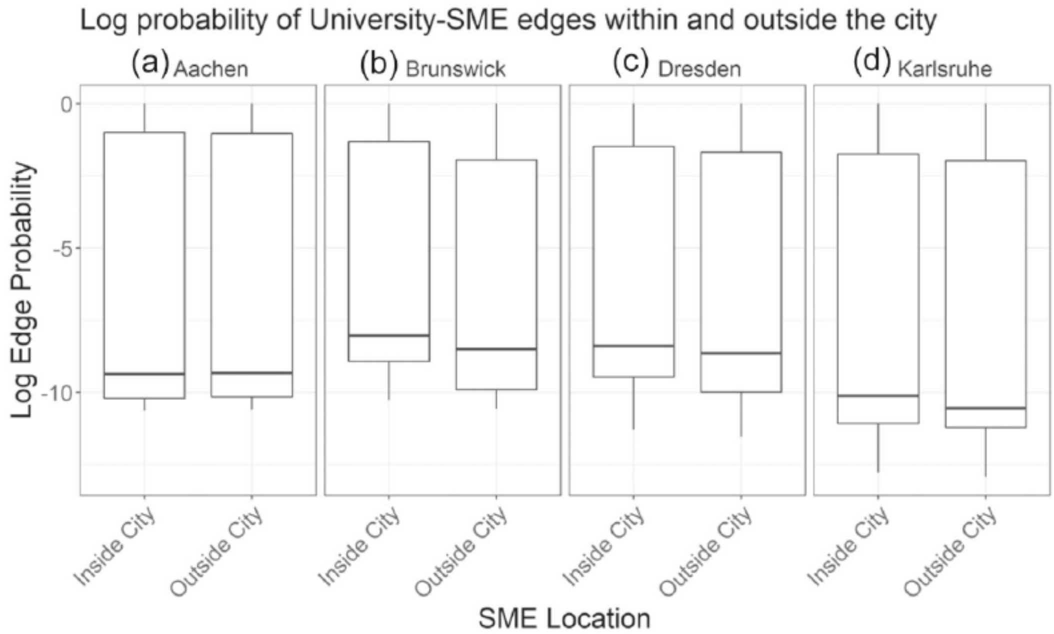

FIGURE 3 Microlevel analysis within city SME–university links. SME, Small- and Medium-sized Enterprise.

5.3 | Microlevel analysis

Following the approach of Leifeld et al. (2018), we conduct a microlevel analysis to supplement the TERGM baseline estimations with the aim to investigate ties between two types of nodes in detail and garner more support for H1. Specifically, we focus on SME–university links to elicit the likelihood of connections on different regional levels.

The plots in Figure 3 show the likelihood for SME–university links. It includes only SMEs located within the same federal state as the university (i.e., belonging to the RIS) and differentiates the location of SMEs being located within the federal state (1) and the core of the RIS, the city (0).[6] We find that an SME–university link within the city is less probable than if the SME is located farther away. The differences are smallest for Aachen and largest for Brunswick. The probabilities are slightly higher for Brunswick and Dresden than Aachen and Karlsruhe. This partially supports H1 stating that links between SMEs and the university in the region are more likely in regions where there are fewer suitable large firms as collaboration partners.

We do the same exercise for SMEs located within the same federal state versus SMEs outside the federal state to account for a larger regional surrounding (Figure A2). For the federal state the university of Brunswick has the highest probability for linking with SMEs when they are located within the same federal state. The probability is lowest for Karlsruhe. This could indicate that SMEs as well as universities form links to other actors. As hypothesized for the regions where there are fewer large firms—as is the case for Dresden and Brunswick—the links within the same federal state point towards a higher regional involvement of the focal university when it comes to SMEs.

To gain a better understanding of the impact of time and to test Hypothesis 3, a microlevel analysis with time lags is conducted (Leifeld et al., 2018). Mean project duration of SMEs is 3.82 years (standard deviation 0.78). Figure 4 shows the results of the analysis with time lags.

The graph shows the average probability of any SME being connected to the focal university before the first actual cooperation at time *t* and after. The probability of collaboration is low in all four regions before and clearly higher at the start of the first collaboration in *t*. Only for Dresden we can see a

[6]The probability distributions are highly skewed and a log-transformation is employed.

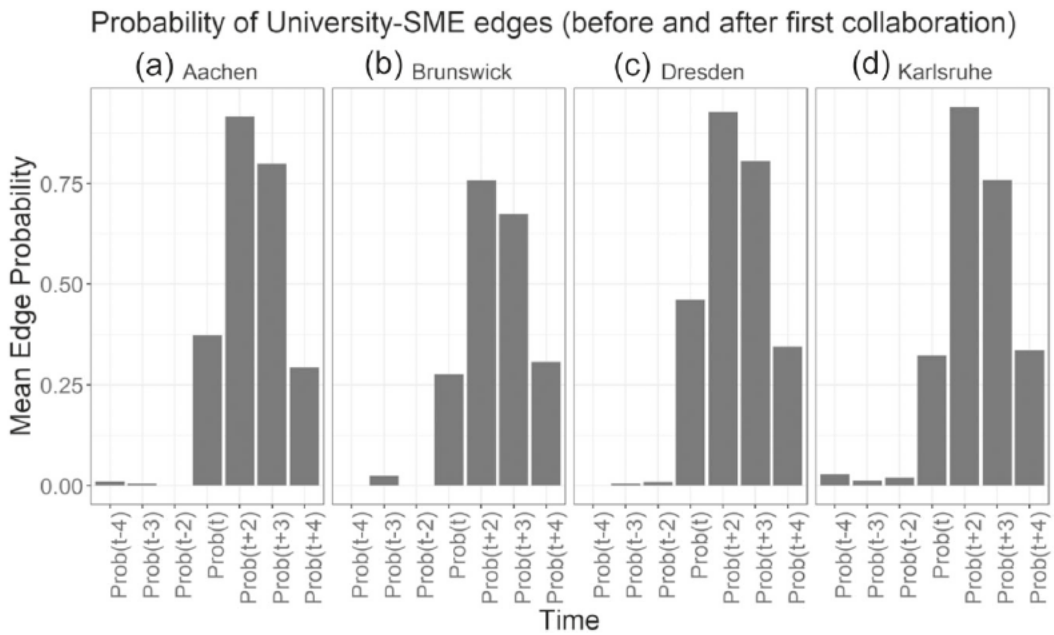

FIGURE 4 SME–university collaboration probabilities over time. SME, Small- and Medium-sized Enterprise.

stepwise increase in the probability before the collaboration although this is very small. There is no discernable regular pattern. For all four regions, the probability is highest 2 years after the initial collaboration and declines consistently until 4 years after the collaboration. The analysis does not differentiate between an ongoing or a new collaboration. Therefore, it is not surprising that the probability stays high up to 3 years, in this case $t + 2$. The probability decreased afterwards showing on the one hand that there are projects lasting longer than 3 years but also indicating that new projects might have already started. We cannot differentiate between the two cases but since multiple consecutive collaboration is possible according to the funding regime and can be found in the data, we can at least partly confirm Hypothesis 3 postulating a rise in the probability of further collaboration after the first one. This highlights the importance of an initial collaboration.

5.4 | Robustness check

To go into more detail about the consecutive collaboration of SMEs in relation to collaboration with the focal university in the RIS we conduct a robustness check. Since the microlevel analysis already covers SME–university collaboration we want to see whether university collaboration enables SMEs to collaborate with other partners (e.g., firms) as well. We do so by comparing two groups of SMEs within each RIS. The "treatment" group has had a collaboration with the focal university, the "control" group did not collaborate with the university before. Similar to the microlevel analysis we choose a time span of 5 years. We test whether these two groups have the same probability of collaborating with a random set of private firms. We draw a sample of 10 SMEs that have collaborated with the focal university before and a sample of 10 SMEs of the RIS which have not. We then draw 20 random private firms and calculate the pairwise edge-probability between the treated and untreated SMEs and each of the 20 private firms. This probability is conditional on the BTERGM model, the node, and network characteristics (Leifeld et al., 2018). We repeat this procedure 10 times amounting to 4000 observations for each RIS. We then conduct a Mann–Whitney *U* test to compare the treated and nontreated SMEs. The results of the robustness check are presented in Figure 5.

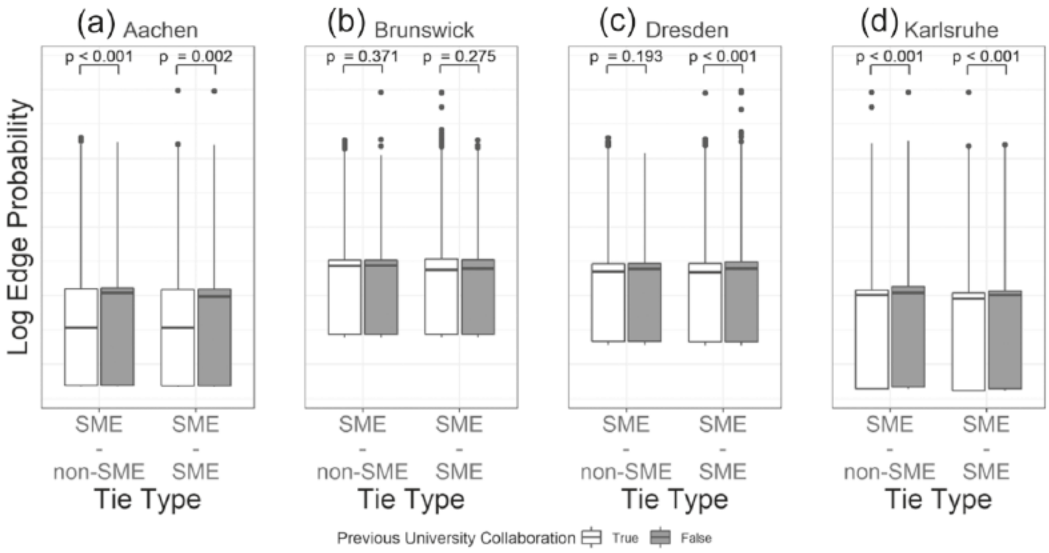

FIGURE 5 Robustness check. SME, Small- and Medium-sized Enterprise.

We show two boxplots for each RIS. The *p* value refers to a Mann–Whitney *U* test for the equality of distributions among the two groups of SMEs. The distributions are significantly different from each other for Aachen ($p = 0.002$), Karlsruhe ($p < 0.001$), and Dresden ($p < 0.001$) in the case of SME–SME links. In the case of Brunswick, we do not find significantly different results for the two groups of SMEs ($p = 0.275$). For the RIS of Aachen, Karlsruhe, and partially Dresden (for ties between SMEs and non-SMEs $p = 0.193$) the probability to collaborate with a random firm and a random SME is higher for SMEs that have not collaborated with the university 5 years before. For Dresden this only holds for SME–SME links but not for larger firms. For Brunswick we do not find significant differences between SMEs having collaborated and not having collaborated. It is conceivable that SMEs which have collaborated with a university are more likely to collaborate repeatedly than to build up collaborations with firms. Because university collaborations are specific in their nature, they increase SMEs' collaboration depth but do not seem to enhance a firm's overall capacity to collaborate more broadly (collaboration breadth; Laursen & Salter, 2004).

6 | DISCUSSION AND CONCLUSION

This paper set out to shed light on the role of universities in collaboration networks and possible implications for the functioning of RIS in the absence or presence of larger firms. To this end we construct and analyze networks from publicly supported research collaborations. We use TERGM to investigate link formation on the basis of node, dyad, and structural level characteristics. Our results indicate that in regions with fewer large firms, universities connect a significant number of small firms in collaboration networks and simultaneously function as connectors to actors outside the region. The latter applies to external firms of varying sizes, universities, research institutions, and other organizations.

However, while we can confirm that universities in all four sample regions are central in the network and play a crucial role in connecting SMEs with actors inside and outside their region, we can find only indirect support for H1 (higher likelihood of link formation with the university by SMEs in regions without large firms). Interestingly, link formation between SMEs and the university is significantly less likely in our most active region, Karlsruhe (in terms of overall nodes in the network). With Dresden and Brunswick having fewer large firms, the universities are more important as cooperation partners. This may also be fueled by personal contacts and mobility between the universities and firms in the region (Fromhold-Eisebith & Werker, 2013). Universities are reputable employers and individuals with an academic background contribute to a firm's knowledge base enhancing the ability to cooperate on the one hand and provide a personal connection on the other hand (Fudickar & Hottenrott, 2019). This personal connection can be crucial when it comes to building trust and bringing different incentive systems together (De Wit-de Vries et al., 2019).

We find weak support for H2 (more indirect ties in the network for SMEs linked to the university) in the TERGM results of structural variables indicating preferential attachment and hinting at some kind of Matthew effect. Because of their enormous outreach potential, universities do provide significantly more indirect ties to SMEs that are linked within the regional core of the RIS (city). Finally, we do find support for H3 (initial SME–university linkages foster future collaborations). Microlevel analyses revealed a lasting effect of initializing a collaboration with the focal university that results in a positive average probability of SMEs to be still linked with the university even 4 years after the collaboration (when most projects are already finished).

In sum, we do find some structural differences for the role of universities in regions with different compositions of small and large firms. However, these are rather in the details and not in an overwhelmingly pronounced distinction. For example, we can confirm the role of universities to connect RIS to other knowledge bases and help local SMEs to overcome resource shortages by providing links to external actors (Fritsch & Schwirten, 1999; Marek et al., 2016). This may relate to universities "third mission" efforts targeting SMEs especially in regions with fewer cooperation possibilities. As our analysis specifically addresses subsidized R&D cooperation policymakers should once more be aware of the effect support schemes can have aside from mere financial support.

Our investigation is also subject to a number of limitations. First, the underlying data of the networks are subsidized collaborations which do not necessarily reflect all connections of actors within an RIS. Moreover, participation in publicly supported funding probably entails a sorting process between successful and unsuccessful applicants. While the composition of the consortia and the decision to apply should at least partially constitute a strategic planning of the organizations, the granting decision clearly does not. It is likely that policymakers and ministries at least indirectly influence formation and change of networks through the selection of projects. However, Fritsch et al. (2018) highlighted that other types of data lead to similar overall patterns of network formation when compared with subsidized projects. A second shortcoming, which is closely related to the data source is our inability to consider other types of collaboration evolving after receiving the collaborative funding. Last but not least, taking egocentric networks of the cities of interest somewhat limits our analysis. For example, we cannot rule out the possibility that local SMEs link up to universities further away (e.g., because of personal ties or curricular relevance for the firm). This would also reflect inflow of "outside" knowledge into RIS, but in a more direct way instead of requiring the local university as a gatekeeper or broker. It remains a desideratum for future research to consider this possibility and consider supraregional link formation between SMEs and universities in more detail.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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