

## Chapter 9

# Topology and Evolution of Collaboration Networks: The Case of a Policy-Anchored District

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Despite all the increased mobility of capital, goods, and labor, modern globalization has failed to produce a placeless market economy. Contrary to expectations, local differences have radically emerged, creating uneven economic landscapes (Amin & Thrift, 1995). Regions and localities increasingly compete to attract and retain resources through innovation (Cooke, 2005; Cooke, Uranga, & Etxebarria, 1997; Morgan, 2007). Innovation, from this perspective, is intended as a collaborative process linking science, technology, industries, and institutions within a coherent system able to produce positive spillovers and favor systemic learning (Asheim, Smith, & Oughton, 2011; Morgan, 2007).

From a theoretical point of view, these interactions are likely to produce vital regional innovation systems with enhanced potential for growth (Doloreux & Parto, 2004). The industrial-cluster model proposed by Porter represented a first concrete example of this process of systemic learning. Since Porter’s conceptualization (Porter, 1998), clusters have become a flagship model for innovation all over the world, inspiring policies in Europe and other OECD countries at all levels as well as in emerging economies. As clusters were replicated and sustained by public policies, there emerged an array of diverse empirical applications reflecting different aims, governance, institutions, and composition. According to Martin and Sunley (2003), however, this organizational variety made the very meaning of the cluster concept vague and pointless, calling for a detailed classification of experiences and practices.

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The initial enthusiasm for clusters gradually thus dampened, and thought turned to the question of what type of connections were really to be encouraged, given that “being connected” is just not enough. Moreover, the promised gains of regional competitiveness were difficult to assess, given that the institutional complexity involved in regional innovation systems could not be easily translated into *competitiveness* as though clusters were firms (Martin & Sunley, 2003). The evaluation of regional innovation systems is even more problematic when clusters’ members have key public targets, as in the case of policy-anchored districts, whose major drivers can be government tenants such as capital cities, military or defense facilities, public universities, or national research centers (Markusen, 1996). The specific issues inherent in these policy-anchored districts still need to be properly addressed.

Researchers contributing to a growing body of studies are investigating social network analysis as an effective means with which to examine the structure and dynamics of regional innovation systems. Collaboration networks represent the backbone of systemic learning. According to Powell et al., (1996), the wider the industrial knowledge base is, the more collaboration networks become essential for exploiting and exploring a firm’s capabilities. Such networks are not one-time dyadic interactions aimed at filling in a firm’s gaps in knowledge. On the contrary, networks are the loci of innovation representing the means through which collective learning unfolds. Studying clusters as networks has therefore become increasingly popular in the literature. Network analysis has been used to explain how the innovative capacity and performance of firms vary with network attributes such as centrality or density (Boschma & Ter Wal, 2007; Giuliani, 2007; Tsai, 2001). Alternatively, network properties and configurations were explained as resulting from firms’ characteristics, such as knowledge bases (Baum, Shipilov, & Rowley, 2003). However, to the best of our knowledge, there are no studies formally analyzing networks as coordination mechanisms administered by a formal local institution devoted to orchestrating the network’s developmental trajectory (Provan, Fish, & Sydow, 2007).

Our study contributes to this literature on regional innovation systems through a formal network analysis of a network-administered, policy-anchored district, *Ingegneria dei Materiali polimerici e compositi e Strutture (IMAST)*, located in the region of Campania in southwestern Italy. Policy-anchored districts are often criticized as suffering from technological and political lock-in, where member organizations are well-established, large corporations primarily interested in consolidating and reproducing a given structure through multiple embedding mechanisms (Tödtling & Trippel, 2005). We want to determine the extent to which a process of consolidation of existing structures applies to IMAST or whether behavioral changes are emerging.

IMAST is a high-tech district focusing on polymeric and composite materials, engineering, and structures. This modern corporate research center was built in 2004 on the initiative of a public university, a national research center, and a set of public and private firms in strategic industries such as aeronautics, transport, and defense. A dedicated administration was established with the explicit mission of orchestrating members’ relations and facilitating the integration of the different

knowledge bases for the common goal of fostering exploratory research on complex polymers.

An ideal core–periphery configuration is taken as a benchmark against which to compare the evolution of the observed patterns of collaborations within the IMAST project network. We conduct a prespecified blockmodel analysis of IMAST’s collaboration network for research and development (R&D) in each of the 7 years from 2006 to 2013 to determine how far its observed topology was from a core–periphery model configuration at each time point (Doreian, Batagelj, & Ferligoj, 2005). The core–periphery model used as a benchmark was defined as a multiple-core model with a bridging core connecting all the others (Kronegger, Ferligoj, & Dorein, 2011).

Blockmodeling can provide a synthetic and effective visualization of the evolutionary trajectory of the cluster. It is thus possible to use prespecified blockmodeling to assess the extent to which the observed trajectory was path dependent. From an evolutionary perspective, we operationalize the concept of structural variations introduced by Glückler (2007) to explain how a developmental trajectory can be shifted away from its path. Lastly, we examine what type of actors occupied key structural positions and what degree of positional mobility there was in the period examined.

The available theories on cluster configuration and evolution are reviewed in the first section, with particular attention to the core–periphery model. The second section introduces the case study characteristics and the data used for the analysis. In the third section we illustrate the method of prespecified blockmodeling and operationalize key indicators of path reproduction and variation. The fourth and fifth sections contain the results of our prespecified blockmodeling analysis, which shows the evolutionary trajectory of IMAST. This part of the chapter also has a detailed discussion of the organizations’ attributes. The final section presents our conclusions and recommendations.

## **Cluster Topologies in the Literature: Generative Processes and Configurations**

Innovation in a knowledge economy is conceptualized as an interactive process of learning that involves different actors in a system (Cooke & Morgan, 1999). This learning process is shaped by a variety of institutional routines and practices, defined as organizational patterns of behavior. The delicate role of managing collaborations and harmonizing practices and routines is particularly sensitive when technology- and science-based organizations are called on to coexist within the same cluster (Autio, 1998). In these cases a dedicated administration can be instituted as a knowledge integrator in the network-administered organizations (NAO) (Provan & Kenis, 2008). The literature on innovative clusters does not directly examine top-down management strategies of collaborations, probably because top-down management is not an ideal model that fits all cases. However, several economic

processes have been identified as generative of cluster topologies from a bottom-up perspective. These processes suggest that a core–periphery structure is the most likely one to emerge in innovation networks.

Owen-Smith and Powell (2004) identified geographical proximity and ownership as the main explanation for cluster configurations. In their view, geographical proximity facilitates informal knowledge transfers by providing trust-based channels of communication. In the absence of face-to-face interactions that are perceived as secure, information needs to be formally protected. Distant knowledge transfers, therefore, are more likely to occur through codified conduits of knowledge regulated by property rights.

These underlying processes have been shown to affect the resulting structure of the network providing different positional advantages to actors. Owen-Smith and Powell (2004), for example, estimated a model using data on the Boston biotechnology industry and showed how geographical proximity and ownership have an impact on centrality. Geographical proximity favored a process of embedding by which groups became cohesive over time. Cohesiveness benefited all members, regardless of their centrality. Conversely, in geographically sparse communities, being central is essential to success. The study by Owen-Smith and Powell showed that ownership also mattered in terms of configuration. When clusters were driven by private commercial firms, networks ties likely spread across the globe to reach key partners. Policy-anchored districts, by contrast, tended to take root in the community to which they belonged, thus creating dense local networks.

The dyad of *local–tacit* versus *global–formal* knowledge transfers was discussed by Bathelt, Malmberg, and Maskell (2004), who argued that both these types of interactions need to coexist. Cognitive proximity is considered in their study as the baseline mechanism of cluster topology. Based on the consideration that collaboration requires a certain degree of cognitive distance, local buzz is seen as a way to reduce distance and acquire familiarity with different knowledge bases. In order to maintain creative diversity within the cluster, it is simultaneously essential to have intakes of fresh information via pipelines connecting the buzz to the rest of the world. Should the buzz prevail, the cluster risks technological lock-in. Should pipelines overmultiply, the cluster risks disintegration. Finding the balance between inward- and outward-looking ties is, therefore, key to sustainable cluster development.

Zooming out from individual ties, we note that the configuration resulting from the process of cognitive recombination is a core–periphery model in which the buzz represents the cohesive nucleus of the topology and the pipelines its periphery. In a study on the wine districts in Italy, Giuliani (2007) also underlined the importance of knowledge bases in producing a core–periphery network configuration. She considered two distinct relations: a knowledge network built on survey data tracing technical advice, and a business network recording any type of business relations among cluster firms. A model was then estimated to understand the effect of knowledge bases and firms' characteristics on degree centrality. Estimation results were reinforced by calculating a core index to locate core actors within the networks. Results showed that the two networks had very different configurations. Although the business network was complete, representing a collective and pervasive

community, the knowledge network was highly centralized, producing a selective and uneven environment. At the core of the knowledge network sat the firms with the strongest knowledge bases.

Furthermore, Balland, Suire, and Vicente (2010) distinguished the effect of geographical proximity and knowledge bases by project phases such as in a knowledge value chain approach. In this very thought-provoking study, two-mode data on the Global Navigation Satellite System in Europe (GNASS) were used to define two network projections. The first network projection, describing project-to-project relations, was used to divide projects into three phases of the knowledge value chain: exploration, integration, exploitation. The second network, showing an organization-to-organization network, was used to distinguish firms by their knowledge bases: synthetic, analytic, and symbolic. Finally, a blockmodel was used to find cohesive local clusters and pipelines linking these clusters to global partners. Results from social network analysis showed that the project network indeed took a core-periphery configuration, the core consisting of exploitative projects close to the marketing phase and with a high concentration of pipelines. By contrast, local embeddedness dominated the periphery where exploratory projects required trust to exchange sensitive information and reach closure.

The relation between the core and the periphery of an innovation network was further discussed by Glückler (2014) with an analysis of BASF's cross-departmental knowledge flow linking the center to a peripheral unit in Argentina. The study demonstrates that the periphery can become a particularly suitable location to develop controversial innovations due to its organizational features. The unit examined was able not only to capitalize on its local market connections to develop a new business model but also to exploit the global organizational viscosity of BASF by establishing contacts with distant units.

From this literature it emerges that geographical and cognitive proximities as well as ownership can set in motion underlying processes that ultimately produce core-periphery structures. The extent to which an observed network approximates a core-periphery model can be captured through blockmodeling. This method is well established in social network analysis and has been used since the 1970s to reduce a network to its key topological features (Doreian et al., 2005). In this chapter, we use a variant of blockmodeling that permits prespecifying a theoretical core-periphery model and then using it as a benchmark against which to measure the configuration of the observed project networks over time.

The temporal dimension is particularly important in this study because it allows one to understand the extent to which the district development trajectory was path dependent (Martin & Sunley, 2006). The presence of a core-periphery structure in a specific moment of a cluster life does not necessarily mean that the structure will persist in the future. In this study we consider the emergence of a core-periphery structure as an indication that an underlying process of preferential attachment is taking place. This process implies that new ties are more likely to form around already central actors, reinforcing the cohesiveness of the core against the periphery (Glückler, 2007). However, this correspondence between topologies and processes persists only if the processes are protracted.

From an evolutionary perspective variations can occur such that the entire system shifts toward a new configuration. Variations are defined as ties (or behaviors) capable of modifying the whole structure because their formation countervails the prevailing reproductive rule of the system. Glückler (2007) identifies three types of variations with potential structural impact: (a) ties that establish global bridges between the local cluster and distant alters (e.g., the pipelines theorized by Bathelt et al., 2004); (b) ties that establish local bridges by connecting groups that are proximate but disconnected (due to gaps in the knowledge bases, for instance); and (c) actors who are part of different groups and act as brokers. All these types of variations are operationalized by making explicit hypotheses on the expected location of block-model inconsistencies. Before we move on to the method, the next section introduces the case study and the data used for the analyses.

## **The Case Study: The Experience of Italian Technological Districts**

Influenced by the theory of regional innovation systems, European policies have encouraged the creation of several R&D infrastructures (Landabaso, Oughton, & Morgan, 1999). In this section we focus on the specific case of policy-anchored technological districts (TDs). As reported in Lazzeroni (2010): “A technological district is defined as a territorial system specialised in hi-tech activities and endowed with factors that determine system innovativeness” (p. 48). In Italy this policy orientation led the Ministry of Education, Universities, and Research to set up 29 TDs between 2002 and 2004. The creation of TDs was the implementation of a region-oriented policy aimed at fostering innovation and competitiveness through “local aggregations of high-tech activities, made up by public research centers, firms and local governments, geographically concentrated” (Bertamino, Bronzini, De Maggio, & Revelli, 2014, p. 6). Thus, TDs are characterized by three elements: territoriality, specialization in high technology, and system innovativeness. TDs represent a key region-oriented policy instrument aimed at stimulating interorganizational collaborations through subsidization (Fornahl, Broekel, & Boschma, 2011).

Even though TDs stem from the same policy, they have different specializations, governance systems, and geographical contexts. Given the high level of heterogeneity characterizing these clusters, cross-cutting comparisons remain problematic (Lazzeroni, 2010; Miceli, 2010). We undertake an in-depth analysis of a specific case study by adopting an evolutionary perspective aimed at capturing changes with respect to a theoretical model (for a related approach, see Prota, D’Esposito, De Stefano, Giordano, & Vitale, 2013; Prota & Vitale, 2014; or Ardivino & Pennacchio, 2012; Capuano, De Stefano, Del Monte, D’Esposito, & Vitale, 2013).

The case study investigated, IMAST, conducts exploratory research on composite materials and polymers engineering. It was conceived as a corporate research center bringing together in horizontal collaborations the largest Italian firms in strategic industries such as defense, aerospace, aeronautics, maritime shipping, and

transport.<sup>1</sup> Beyond this highly technological core, the district was also given a science base through involvement of public universities and the national research institute. The governance was a holding of industrial and public laboratories and institutes. This holding was managed by a dedicated administration whose role was to orchestrate collaborations to promote horizontal partnerships and encourage the recombination of knowledge bases. The explicit mission of the district, as knowledge integrator, was to intensify public-private collaborations and to put in place private-to-private interactions connecting firms from different industries within and outside the district.<sup>2</sup>

This cross-sectoral approach to baseline research was orchestrated by the administration through active management of the network. Not only were projects selected, but district members and external partners were called upon to participate in order to encourage the convergence between science and technology. IMAST management was able to attract an increasing number of firm leaders (the number doubled during the 10 years examined), and the science base was expanded to involve an increasing number of departments, universities, and institutes. In the following section the R&D collaboration network among members is first defined and then analyzed by means of social network analysis.

The data in this chapter refer to all IMAST R&D projects subsidized by both national and international grants. These projects can be used to study the structure of collaboration networks linking members among themselves and with the rest of the world.<sup>3</sup> They also express IMAST's policy on collaboration insofar as they were the direct result of the administration's innovation strategy.

The data encompass 24 R&D research projects undertaken by the district between 2006 and 2013. These project data constitute a two-mode network of organizations participating in projects. More formally, let  $N$  be the set of  $n$  TD's members (associated members and external partners) and  $P$  be the set of the  $p$  R&D projects observed for the  $n$  members over time. An affiliation matrix  $A(n \times p)$  can be defined. The matrix entry  $a_{ik}$  is equal to 1 if the organisation  $i \in N$  participates in the project  $k \in P$ , and is equal to 0 otherwise.

We use the conversion approach (Everett & Borgatti, 2013) to obtain an actor-by-actor adjacency matrix  $G$  from the two-mode network. In matrix  $G$  the entries are equal to the number of research projects shared by two organizations and 0 if two organisations have never collaborated in a research project. In order to highlight the structural changes that occurred over time, separate adjacency matrices were derived for each year (Prota & Vitale, 2014). Each of these temporal slides can be described as a graph  $G_T(N, L, T)$ , with  $T$  being the set of ordered time points  $t \in T$ . The set of actors  $n \in N$  and the links  $l \in L$  change over time according to individual participation in the projects.

<sup>1</sup>[http://www.imast.biz/index.php?option=com\\_content&view=article&id=1&Itemid=2&lang=en](http://www.imast.biz/index.php?option=com_content&view=article&id=1&Itemid=2&lang=en)

<sup>2</sup>The governance structure, the rules, and the composition of the district were highlighted by the manager during an in-depth interview held in February 2014. In particular, the active role of management was clarified by the manager and further discussed with members.

<sup>3</sup>We thank the TD's administrative staff who helped us update the data to March 2013.

In Table 9.1 some whole network measures are provided for each yearly collaboration network examined.<sup>4</sup> The table shows two main waves of funded projects: an initial wave in 2006–2007 when six and seven projects were funded, respectively; and a second wave in 2013 when seven projects started. The number of organizations involved in the collaboration network notably increased over time, going from 19 organizations in 2006 to 82 in 2013. The proportion of associated members to external partners also changed dramatically. From 2006 to 2011, most of the organizations were local research institutions and firms formally engaged with the TD. In 2012 and 2013, the number of external partners exceeded that of associated members. However, the number of the external partners involved in the European R&D project since 2008 is much larger (50 organizations) and has been shrunk to only one representative node in order to simplify the analysis.<sup>5</sup>

Figure 9.1 shows the evolution of the collaboration network. Structural hole measures were used to highlight group clustering.<sup>6</sup> These measures provide information on (i) dyadic constraint, which indicates the extent to which a single organization bridges two cohesive groups; and (ii) associated constraint, which measures the degree of organizational embeddedness within a cohesive group. In the graphs, TD members with high aggregate constraint are drawn closely together, whereas low dyadic constraint is shown as longer links to highlight structural holes.

We note that the one-mode projection of the data has generated perfect cliques in correspondence with joint participation in projects. However, clustering cannot be entirely attributed to this data distortion. Since the very beginning of the TD, a subset of organizations have collaborated on more than one project, suggesting the emergence of a substantially cohesive core. Furthermore, key brokers have characterized the network in each time period. In the start-up phase, only two actors within the TD bridged otherwise disconnected groups. From 2009 onward, however, the number of brokers notably increased.

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<sup>4</sup>We calculated the reported measures by disregarding isolates (the TD's members not involved in projects in each year).

<sup>5</sup>Given that only six members were involved in the EU project, we decided to subsume all the international partners in one representative node. In this way the pattern of collaborations internal to the TD remained stable, and at the same time the analyses and visualizations were simplified. If we were to count all the partners involved in the European project, the number of external partners collaborating with the TD since 2008 would increase by 50 units.

<sup>6</sup>Pajek software for social network analysis (de Nooy, Mrvar, & Batagelj, 2011) was used for all analyses and visualizations in the study.

**Table 9.1** The IMAST<sup>a</sup> collaboration network, 2006–2013

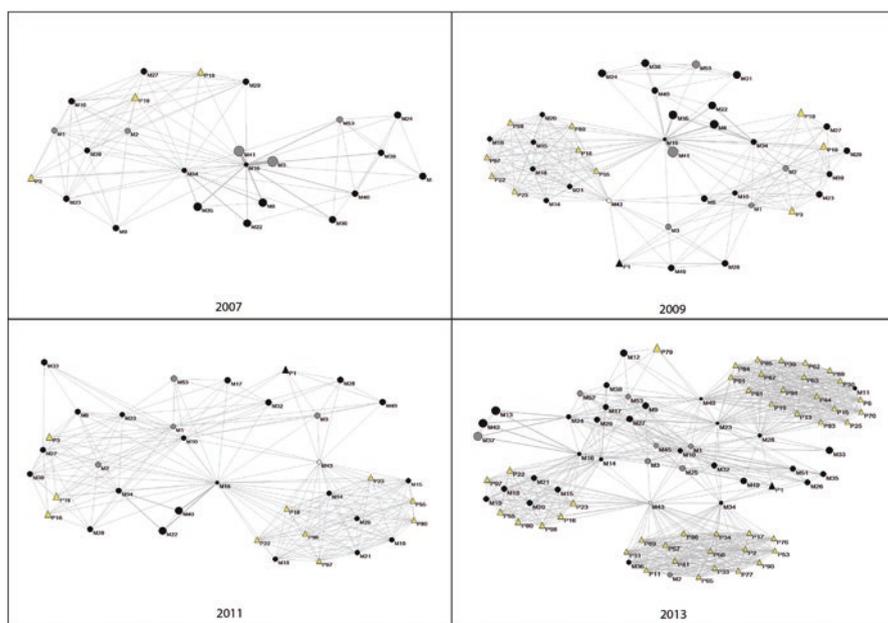
Characteristics	2006		2007		2008		2009		2010		2011		2012		2013	
	Time 2	Time 3	Time 4	Time 5	Time 6	Time 7	Time 8	Time 9	Time 10	Time 11	Time 12	Time 13	Time 14	Time 15	Time 16	Time 17
No. of members	19	24	28	40	39	37	50	82								
No. of associated members	18	21	24	29	28	26	24	38								
No. of partners	1	3	4	11	11	11	26	44								
No. of edges	65	96	116	215	214	218	382	728								
New projects	6	5	1	1	0	2	1	7								
Active projects	7	12	13	13	11	10	8	12								
Density	.38	.348	.307	.276	.289	.327	.312	.219								
Average degree	6.84	8	8.29	10.75	10.97	11.78	15.28	17.76								

<sup>a</sup>Ingegneria dei Materiali polimerici e compositi e Strutture (technological district). *Source.* Authors' elaborations based on R&D collaboration data within the technological district

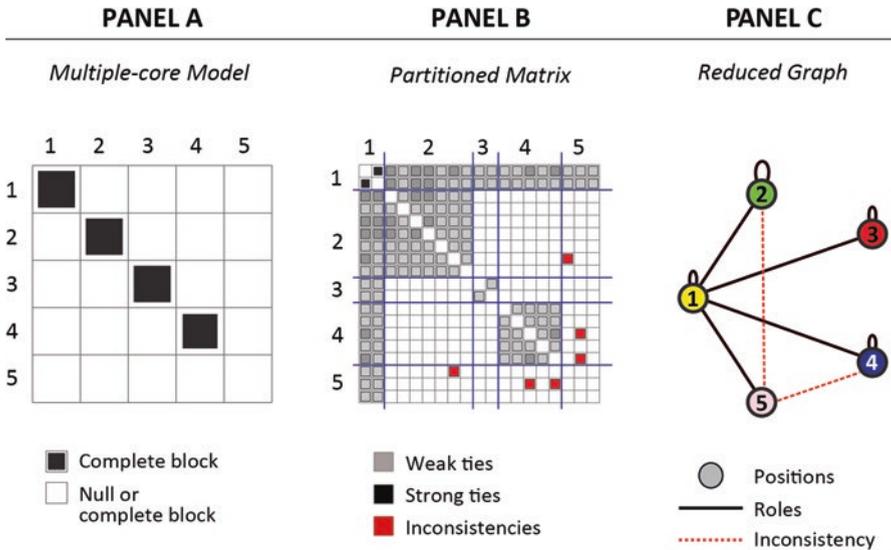
## Capturing Cluster's Topology with Prespecified Block-Modeling

We used prespecified blockmodeling to gain a synthetic view of the structural evolution of IMAST collaboration network (Fig. 9.1). Blockmodeling is a type of clustering for relational data intended to reduce complex networks into simpler graphs, with nodes representing groups of equivalent actors (positions) and ties representing the relation between positions (roles) (see Ferligoj, Doreian, & Batagelj, 2011; Wasserman & Faust, 1994). These reduced graphs (also called images) are used in this study to facilitate synthetic visualization of the overall topology of the IMAST collaboration network and its evolution.

To reduce a complex network into its image, a single node subsumes similar actors if they are equivalent. This study uses the definition of structural equivalence to reduce IMAST collaboration networks. Actors are considered equivalent if their pattern of ties to and from alters is identical (Lorrain & White, 1971). In practice, when structural equivalence is used, the network matrix is permuted to form either null or



**Fig. 9.1** Energized graphs by structural-hole measures of collaboration networks in selected years (2006, 2009, 2011, 2013). *Nodes* represent the IMAST's associated members and external partners; *line lengths*=dyadic constraint; *node size*=aggregate constraint; *node shape*=IMAST's associated member (*circle*), partner (*triangle*); *node color*: firm (*gray*), research institution (*black*), other organizations (*white*), and external partner (*yellow*) (Source: Authors' elaborations based on R&D collaboration within the technological district)



**Fig. 9.2** An example of network reduction through prespecified blockmodeling. *Panel A*: A theoretical multiple-core model. *Panel B*: The multiple-core model fit to data. Inconsistencies between observed and expected ties are marked in red. *Panel C*: An example of reduction where the partitioned matrix in *Panel B* is presented as a reduced graph (Source: Authors' elaborations based on R&D collaboration within the technological district)

complete blocks (Batagelj, Ferligoj, & Doreian, 1992; Doreian et al., 2005). The term *block* refers to the ties linking equivalent actors to alters in this permuted matrix.

In prespecified blockmodeling, a hypothesis on the overall configuration of the network is formulated a priori on theoretical grounds. Subsequently, this model configuration is fit to the data by means of a local optimization algorithm. The algorithm partitions the network to minimize the overall number of inconsistencies between the expected and observed ties. Lastly, the permuted matrix can be reduced to a simpler graph (the image), which represents an instance of all the possible configurations compatible with that prespecified block model.

Figure 9.2 presents the prespecified block model used to reduce IMAST networks (Panel A) and exemplifies the process of reduction (Panels B and C). Panel A reports, in a matrix format, the multiple-core blockmodel specified to fit the data. This particular blockmodel was introduced by Kronegger et al. (2011) to study collaboration among Slovenian academics. The rows and the columns of the matrix in Panel A represent groups of organizations, whereas the cells of the matrix indicate how these groups are related to each other (i.e., the role they play in the system). As mentioned, we specified the groups to be formed according to the definition of structural equivalence.

The topological hypothesis advanced by this blockmodel is that multiple cores of completely connected actors exist in the observed network. We express this hypoth-

esis formally by specifying that diagonal blocks are complete. In our specific case, these diagonal cores can be interpreted as research units or project partnerships. In keeping with Kronegger et al. (2011), these cores are hereafter referred to as *simple cores*.

Furthermore, the blockmodel allows simple cores either to be connected to each other through bridging blocks or to stay disjointed. In our specification, off-diagonal blocks can be either null or complete. The former condition is the case when no overlapping exists between two research groups, whereas the latter condition signals brokerage.

The final block (5,5) of the blockmodel representing the periphery of this multiple-core blockmodel is left unspecified so that it can be either complete or null. The network will have a periphery if the last block is null, implying that the actors in the respective cluster 5 will have no relations among themselves. Pajek software for social network analysis was used to fit IMAST project networks to this block model at each time point.

Panel B of Fig. 9.2 reports how the blockmodel fits the IMAST collaboration network in the year 2006. As mentioned, the observed network was permuted using structural equivalence so that organizations (rows and columns of the network matrix) formed either complete or null clusters (identified by blue lines in Panel B). The cells of the network report the number of times actors collaborated with each other. The higher the number of collaborations, the more intense the color.

Inconsistencies between the observed network and the blockmodel hypothesis are reported in red. The location and pattern of inconsistencies can be examined to arrive at a substantive interpretation of blockmodeling solutions (Prota & Doreian, 2016). More specifically, in this study inconsistencies are used to operationalize the key concepts of *cohesive cores* and *structural variations* as discussed in the first section as follows:

1. Complete diagonal blocks with no inconsistencies refer to clusters whose members collaborated on exactly the same research projects or on a single research project. All the organizations participating in the same R&D project are, by definition, collaborating with one another and form a complete clique or a 1-covered block.
2. Complete diagonal blocks with inconsistencies indicate effective cohesive cores. Through the use of structural equivalence, inconsistencies in a complete diagonal block imply nonidentical patterns of ties between a cluster's organizations. In other words, organizations recursively collaborate in slightly different partnerships.
3. A diagonal core is a bridging core when all the off-diagonal blocks associated with it are complete. This operationalization applies to block (1;1) in Panel B of Fig. 9.2, whose associated columns and rows are all complete. In our example the two research institutions in cluster 1 collaborated on all the projects undertaken by the district. By identifying a specific group of organizations participating in all research projects, bridging cores can be taken as a measure of local brokerage as discussed by Glückler (2007).

4. Inconsistencies in null off-diagonal blocks identify brokerage. An example of this pattern of collaboration is shown by the red ties in block (2;5) and (4;5). These inconsistencies show that individual organizations in clusters 2 and 4 are also taking part in the projects undertaken by the organizations in cluster 5. These organizations cross a structural hole.

Note that all the inconsistencies reported in Panel B involve the peripheral block (5;5), which happens to be null for that year. In other words, the network in 2006 indeed took a classic core–periphery structure with a bridging core (block (1;1)) and a disconnected periphery (block (5;5)). An increased number of inconsistencies involving actors in cluster 5 will ultimately have an impact on the core–periphery structure of the network by eliminating the periphery. In that eventuality, this local bridging would represent a structural variation (Glückler, 2007).

Finally, Panel C of Fig. 9.2 illustrates an example of network reduction by which the rows and columns of the partitioned network matrix in Panel B are shrunk to single nodes if they are equivalent. The reduced graph represents the observed configuration consistent with the prespecified blockmodel. In the reduced graph, nodes with loops represent simple cores (complete diagonal blocks in Panel A), whereas ties indicate cross-cluster bridging. Dotted red lines indicate a discrepancy between the network observed and the ideal core–periphery model tested.

## Blockmodeling Results

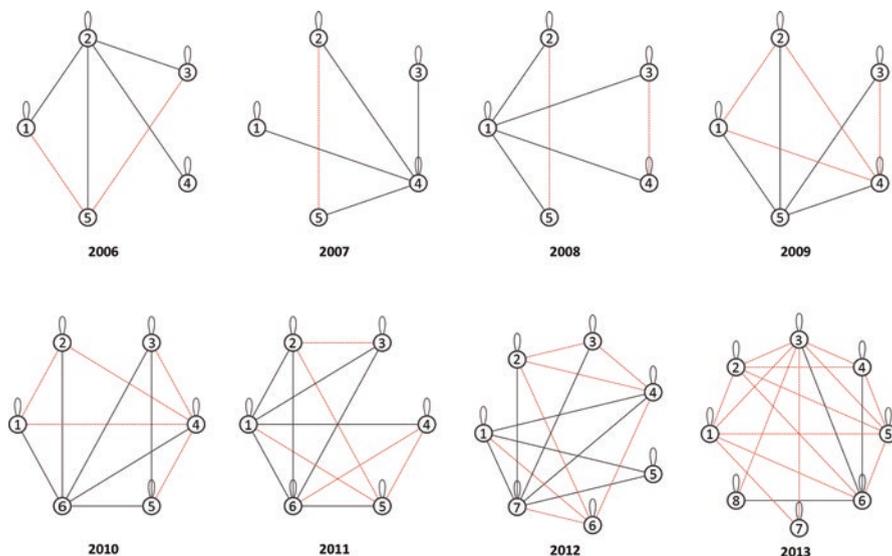
The blockmodel specified in the previous section is used to reduce the observed networks (as illustrated in Fig. 9.3) in each year from 2006 to 2013.<sup>7</sup> The reduced graphs obtained are presented in Fig. 9.3.

Empirical results confirm that a process of structural transition characterized the evolutionary trajectory of the IMAST collaboration network. Between 2006 and 2009, the network configured as a core–periphery model with few inconsistencies. In each year of that period, it was possible to identify a clear bridging core linking all the other clusters in a star configuration. Moreover, during those years, there were only a few cross-cutting ties connecting clusters beyond the bridging core, and they were all defined as inconsistencies (reported as red ties in Fig. 9.3). Lastly, from 2006 to 2008, a clear periphery was identified. Members of cluster 5 did not have collaborations among themselves (there was no loop on the cluster), but they did have systemic ties with the bridging core and sporadic ties with other clusters (inconsistencies).

In 2009 there occurred a variation capable of shifting the network evolutionary path toward a new configuration. The shift is signaled, among the other things, by

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<sup>7</sup>An increasing number of clusters (from 4 to 10) were used for reduction. Only the best solutions are reported. The chosen solutions are those that minimize the number of clusters and inconsistencies and still provide stable results. One thousand repetitions were done for each fit.



**Fig. 9.3** Reduced graphs of IMAST collaboration networks over time. *Nodes* represent clusters of structurally equivalent actors; *links* represent intergroup relations; loops signal within-group connections. *Red ties* signal positive ties in blocks specified as null (bridging ties) (Source: Authors' elaborations based on R&D collaboration within the technological district)

the fact that the periphery (cluster 5) suddenly became the bridging core. Figure 9.3 shows that in 2009 cluster 5 was connected to all the other clusters but it had no loop. That is, its members were disconnected from each other, but they have become key structural brokers within the network. This result alone calls into question the very concept of network periphery. In addition, in 2009 a new bridging core emerged from the inconsistencies in cluster 4. The new bridging core indicates that inconsistencies were becoming structured and that a new collaboration pattern was being established from below.

From 2010 onward, the development trajectory of IMAST remarkably phased away from a core–periphery model, and the pattern identified in 2009 gradually evolved into a new trajectory. In 2010 cluster 6 represented the main bridging core; like cluster 5 in 2009, it also had no loop. This evidence further confirms that structural transformations were taking place at the periphery of the network. Moreover, in 2010 cluster 4 remained a bridging core connected through inconsistencies, just as it was in 2009.

This process of transition from a classic core–periphery model culminated in 2011, when the periphery suddenly disappeared. From 2011 to 2013, all clusters had loops, indicating that intercluster collaborations were occurring. The hypothesis that a core–periphery structure persisted from 2006 to 2013 can therefore be rejected. Instead, the collaboration network evolved toward a new model characterized by multiple bridging cores and an increasing number of sporadic ties linking

clusters to one another. In 2012 a third bridging cluster emerged (cluster 3), whereas in 2013 the institutional bridging function seemed to have lost out to increasingly diffused bridging ties captured by the model as inconsistencies.

In the next section the pattern and location of inconsistencies are examined to aid in understanding what types of variations occurred and what types of actors were involved in this process of recombination.

## Inconsistency Analysis and Structural Variations

This section includes an in-depth analysis of inconsistencies to aid in understanding (a) what types of variations shifted the IMAST development trajectory from a core-periphery to a multiple cores topology as discussed in the immediately preceding section (Results) and (b) what types of actors were involved in terms of knowledge bases and geographical location.

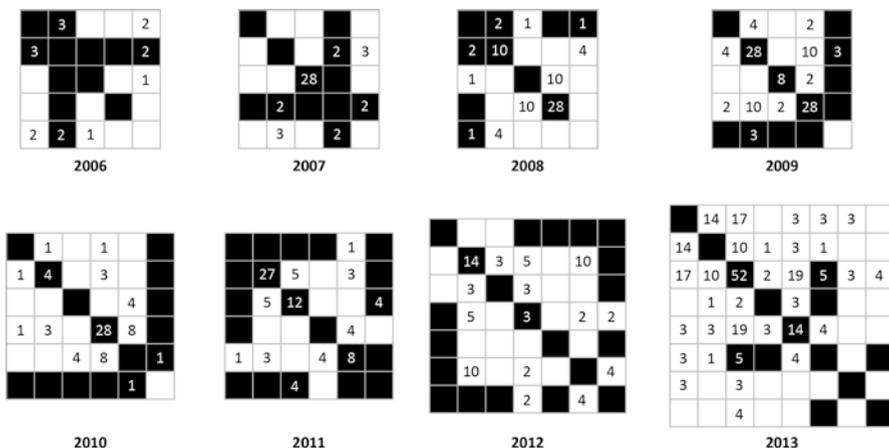
Inconsistencies in blockmodeling do not have a straightforward interpretation. A blockmodel solution cannot be accepted or discarded based on the number of inconsistencies it produces (Doreian et al., 2005). The number of inconsistencies depends mostly upon the shape of the block (Prota & Doreian, 2016). Rather, inconsistencies need to be interpreted in the light of the equivalence chosen for the reduction. From this perspective, inconsistencies indicate where and how the observed network deviates from the specified block model. With this consideration in mind, we have used blockmodel inconsistencies in this study to operationalize structural variations such as local and global bridging.

To explore the location of the inconsistencies the data produced, we examine the inconsistencies matrices as reported in Fig. 9.4. The matrices offer an alternative visualization of the reduced graph presented in Fig. 9.3 and highlight different aspects of the solutions. Although graphs provide an immediate idea of the evolutionary trajectory of the network, matrices allow a more detailed analysis of inconsistencies' locations. In each reduced matrix of Fig. 9.4, rows and columns represent clusters of similar organizations (nodes in the graphs of Fig. 9.3), and cells represent relations between clusters representing ties in the graphs of Fig. 9.3. Matrix's cells are hereafter referred to as blocks (row #; column #). Black cells indicate complete blocks, and white cells represent null blocks. Numbers indicate inconsistencies.

As expected, complete diagonal blocks without inconsistencies identify organizations collaborating on a single project. We refer to these project groups as simple cores. Simple cores are, for instance, all diagonal blocks in year 2006; block (1;1) in 2009; and all diagonal blocks but blocks 3;3 and 5;5 in 2013.

We defined cohesive cores as complete blocks on the main diagonal with inconsistencies. Examples include block (3;3) in 2007, blocks (2;2), (3;3), and (5;5) in 2011, and blocks (3;3) and (5;5) in 2013, as in Fig. 9.4.

Beyond simple and cohesive cores, the blockmodel also identified bridging cores. Particularly central to the system of collaboration are block (4;4) in 2007, block (5;5) in 2009, and block (6;6) in 2010. These clusters are peculiar insofar as



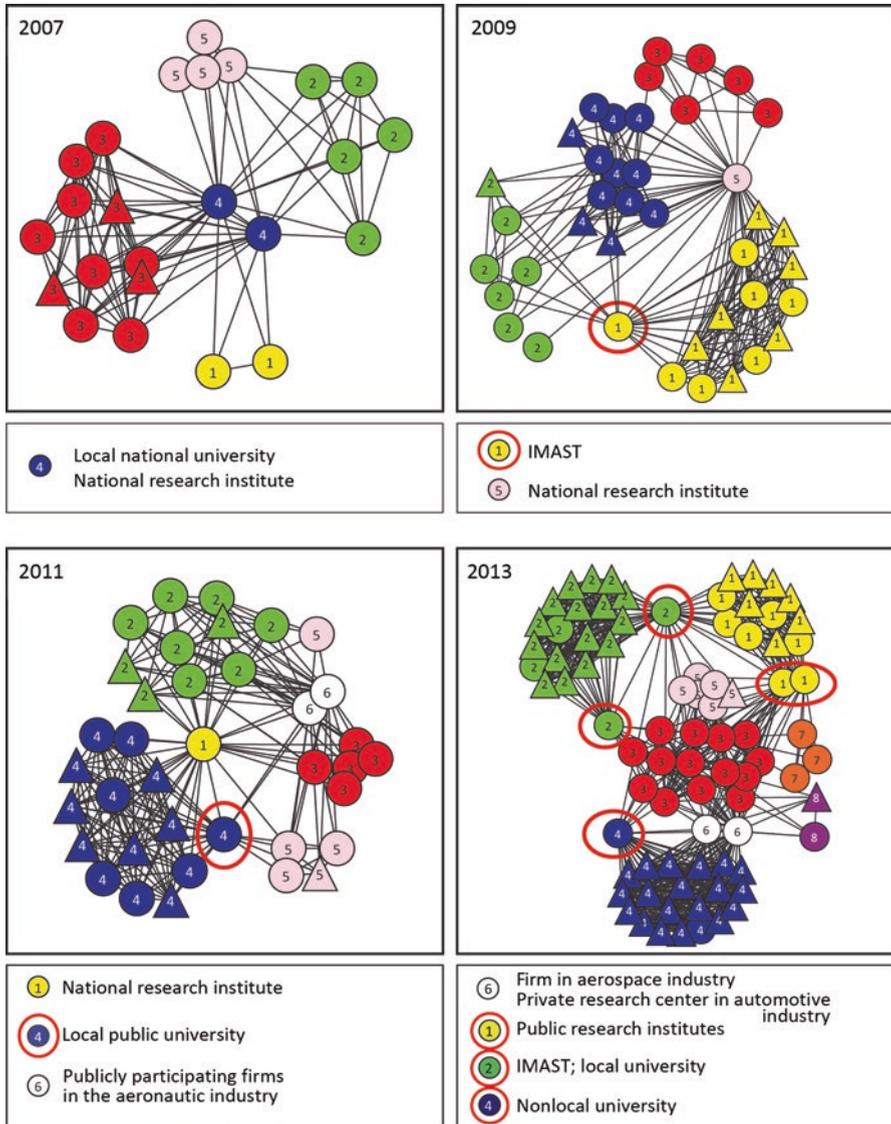
**Fig. 9.4** Image matrices of IMAST collaboration networks over time. *Black* cells represent complete blocks; *white* cells represent null blocks; *numbers* indicate inconsistencies between observed and expected ties (Source: Authors' elaborations based on patterns of R&D collaboration within the technological district)

they included only a few organizations linked by strong collaborative ties involving all other clusters (all the blocks on the associated rows and columns are complete). These key bridging cores had ties spanning all the other research units and played the role of pivots for the whole collaboration network.

Finally, the number of positive ties in null blocks signals that individual brokerage was occurring. Figure 9.4 shows that there was a systemic and generalized increase in this type of inconsistency over time. In 2013, inconsistencies spread across full rows and columns in correspondence with cores. This pattern suggests that a single organization acted as a broker linking more cores, as if it were a bridging core embedded within another type of core. Examples are provided by blocks (1;1), (2;2) and (3;3) in 2013 whose associated rows and columns present a significant number of inconsistencies.

To verify this substantive interpretation of the results further, blockmodeling partitions are fitted onto the original network data. In Fig. 9.5, the observed collaboration networks in selected years (2007, 2009, 2011, 2013) are shown by means of blockmodeling partitions.

The changes that occurred within the main cohesive core can be appreciated in Fig. 9.5. Whereas in 2007 all cores were exclusively connected to the bridging core (block (4;4)), in 2013 a large group of local organizations was right in the middle of the graph (red nodes in Figure 9.5, diagonal block 3;3 in Figure 9.4) and was linked to a number of other cores. This group fully represented the heterogeneity of knowledge bases in IMAST: firms from the defense, aeronautics, maritime, transport, aerospace, and automotive industries, and public universities were all embedded within this cluster along with private research centers and universities.



**Fig. 9.5** Energized graphs of four collaboration networks (2007, 2009, 2011, 2013). *Circular nodes* represent the technological district’s associated members; *triangles* are partners from a different geographical region or nation. *Numbers* indicate clustering partitions. *Red circles* around nodes indicate bridging through inconsistencies (Source: Authors’ elaborations based on patterns of R&D collaboration within the technological district)

The graphs in Fig. 9.5 clearly illustrate the transformations related to the role played by the bridging core within IMAST. In 2006 and 2007, the bridging core was the very center of the network. Cluster 4 included the local public university (under whose initiative the district was first instituted) and the national public research institute. In 2009 and 2010 the local public university entered the cohesive block (4;4) (blue nodes in Figure 9.5, block 4;4 in Figure 9.4). The bridging core (pink node in Figure 9.5, block 5;5 in Figure 9.4) was composed, instead, of the national public research institute alone. The district itself, took part in a large European project together with some of the district members, acting as an institutional global broker between the European partners and the district (yellow node circled in red in Figure 9.5, block 4;4 in Figure 9.4). In 2011 a further bridging core emerged within the system, encompassing two firms (white nodes in Figure 9.5, block 6;6 in figure 9.4).

Lastly, in 2013, the only bridging core remained was this block (6;6) that included a firm and a private research center from two different industries (aerospace and transport). Collaboration, however, assumed a completely new pattern because many actors individually connected cores one another, as was the case with two public research institutes (circled in red) from cluster 1. Similarly, in cluster 2 both IMAST itself and the local public university had explicit brokerage functions. In cluster 4, a university from another region linked the cohesive cluster with the rest of the project members, acting as a global broker.

These ties linking individual organizations from a core with all the members of other cores account for the generalized increase in the inconsistencies reported in the matrix of Fig. 9.4. We have circled these broker organizations in red to indicate that their behavior is inconsistent with the model. It is worth noting that, in 2013, broker organizations connected the local cohesive core (circles) with actors external to the district (triangles). This global brokerage very much recalls the buzz-and-pipeline configuration described by Bathelt et al. (2004).

These results support the conclusion that IMAST is characterized by a clear structural transition from a core-periphery topology toward a new buzz-and-pipeline configuration.

## Conclusions

We have tackled the problem of analyzing the topology and evolution of collaborations within a policy-anchored district by using prespecified block modeling. Through analysis of the patterns of collaboration established during the period from 2006 to 2013, our study has traced the evolutionary trajectory of IMAST's R&D collaborations. Given that collaborations were actively managed by the administration, the study has also provided an assessment of the district's governance and inherent innovation policy.

We used prespecified blockmodeling to define a benchmark topology against which to measure structural changes. Empirical results clearly show that the IMAST

collaboration network evolved from a neat core–periphery structure toward a new structural topology characterized by an increasing number of local and global brokers’ ties. This new topology closely resembles the buzz-and-pipeline model described by Bathelt et al. (2004).

In analyzing this structural change, we have taken an evolutionary approach that takes both retention mechanisms and variations into account (Glückler, 2007). Among the retention mechanisms, the analysis identified the formation of a large cohesive core representing key knowledge bases of IMAST. Examining the changing composition of this cohesive core over time, we found an increasing integration of the science and technology bases. The core included not only private and public firms but also a growing number of university departments and research institutions. The convergence of knowledge bases through joint research activities undertaken at the core of the district remained a constant characteristic of the district’s development.

In addition to this cohesive core, a bridging core also characterized the system at its initial phase. This bridging core can be thought of as IMAST’s institutional base constituted by the main local university and the national research institute. Over time, however, not only did the composition of the bridging core change to include firms, but new broker organizations also emerged. By 2013 the bridging function spread across clusters and became a characteristic behavior of broker organizations crossing structural holes rather than an institutional function. We note also that, although the original bridging core linked local cores to one another, new bridging ties linked the local cohesive core to external partners as in a buzz-and-pipeline model (Bathelt et al., 2004).

From a policy perspective, the structural analysis undertaken in this study is important because it allows an assessment of how the network was governed over a 10-year period. The structural changes were the result of an active administration pursuing a coherent development strategy.

A similar analysis can be replicated in other contexts to compare developmental trajectories across other policy-anchored districts in Italy and beyond. If undertaken, such study would probably open new questions about the variety of topologies of innovation networks and the role local institutions play in managing the structural transitions from one topology to another.

## References

- Amin, A., & Thrift, N. (Eds.). (1995). *Globalization, institutions, and regional development in Europe*. Oxford: University Press.
- Ardevino, O., & Pennacchio, L. (2012). *Le determinanti della cooperazione nei distretti tecnologici italiani finanziati dal governo* [The determinants of cooperation in government-sponsored innovation networks: Empirical evidence from Italian technological districts]. *Studi Economici*, 108, 121–149. doi:10.3280/STE2012-108004
- Asheim, B. T., Smith, H. L., & Oughton, C. (2011). Regional innovation systems: Theory, empirics and policy. *Regional Studies*, 45, 875–891. doi:10.1080/00343404.2011.596701

- Autio, E. (1998). Evaluation of RTD in regional systems of innovation. *European Planning Studies*, 6, 131–140. doi:10.1080/09654319808720451
- Balland, P., Suire, R., & Vicente, J. (2010). *How do clusters/pipelines and core/periphery structures work together in knowledge processes?* Papers in Evolutionary Economic Geography (PEEG), #10.08. Retrieved from <http://econ.geo.uu.nl/peeg/peeg1008.pdf>
- Batagelj, V., Ferligoj, A., & Doreian, P. (1992). Direct and indirect methods for structural equivalence. *Social Networks*, 14, 63–90. doi:10.1016/0378-8733(92)90014-X
- Bathelt, H., Malmberg, A., & Maskell, P. (2004). Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation. *Progress in Human Geography*, 28, 31–56. doi:10.1191/0309132504ph469oa
- Baum, J., Shipilov, A., & Rowley, T. (2003). Where do small worlds come from? *Industrial and Corporate Change*, 12, 697–725. doi:10.1093/icc/12.4.697
- Bertamino, F., Bronzini, R., De Maggio, M., & Revelli, D. (2014). *Local policies for innovation: The case of technology districts in Italy*. Bank of Italy. Retrieved from <http://www.bancaditalia.it/pubblicazioni/altri-atti-convegni/2014-innovazione-italia/Bertamino-Bronzini-DeMaggio-Revelli.pdf>
- Boschma, R. A., & Ter Wal, A. L. J. (2007). Knowledge networks and innovative performance in an industrial district: The case of a footwear district in the south of Italy. *Industry and Innovation*, 14, 177–199. doi:10.1080/13662710701253441
- Capuano, C., De Stefano, D., Del Monte, A., D'Esposito, M. R., & Vitale, M. P. (2013). The analysis of network additionality in the context of territorial innovation policy: The case of Italian technological districts. In P. Giudici, S. Ingrassia, & M. Vichi (Eds.), *Statistical models for data analysis* (pp. 81–88). Heidelberg: Springer International Publishing.
- Cooke, P. (2005). Regionally asymmetric knowledge capabilities and open innovation: Exploring 'Globalization 2'—A new model of industry organisation. *Research Policy*, 34, 1128–1149. doi:10.1016/j.respol.2004.12.005
- Cooke, P., & Morgan, K. (1999). *The associational economy: Firms, regions, and innovation*. Oxford: University Press.
- Cooke, P., Uranga, M. G., & Etxebarria, G. (1997). Regional innovation systems: Institutional and organizational dimensions. *Research Policy*, 26, 475–491. doi:10.1016/S0048-7333(97)00025-5
- De Nooy, W., Mrvar, A., & Batagelj, V. (2011). *Exploratory network analysis with Pajek* (rev. and expanded 2nd ed.). Cambridge, UK: University Press.
- Doloreux, D., & Parto, S. (2004). *Regional innovation systems: A critical synthesis* (Discussion paper No. 2004–17). United Nations University Institute for New Technologies, INTECH. Retrieved from <http://www.intech.unu.edu/publications/discussion-papers/2004-17.pdf>
- Doreian, P., Batagelj, V., & Ferligoj, A. (2005). *Generalized blockmodeling*. Cambridge, UK: University Press.
- Everett, M. G., & Borgatti, S. P. (2013). The dual-projection approach for two-mode networks. *Social Networks*, 35, 204–210. doi:10.1016/j.socnet.2012.05.004
- Ferligoj, A., Doreian, P., & Batagelj, V. (2011). Positions and roles. In J. Scott & P. J. Carrington (Eds.), *The SAGE handbook of social network analysis* (pp. 434–446). Thousand Oaks: Sage.
- Fornahl, D., Broekel, T., & Boschma, R. (2011). What drives patent performance of German biotech firms? The impact of R&D subsidies, knowledge networks and their location. *Papers in Regional Science*, 90, 395–418. doi:10.1111/j.1435-5957.2011.00361.x
- Giuliani, E. (2007). The selective nature of knowledge networks in clusters: Evidence from the wine industry. *Journal of Economic Geography*, 7(2), 139–168. doi:10.1093/jeg/lbw020
- Glückler, J. (2007). Economic geography and the evolution of networks. *Journal of Economic Geography*, 7, 619–634. doi:10.1093/jeg/lbm023

- Glückler, J. (2014). How controversial innovation succeeds in the periphery? A network perspective of BASF Argentina. *Journal of Economic Geography*, *14*, 903–927. doi:[10.1093/jeg/lbu016](https://doi.org/10.1093/jeg/lbu016)
- Kronegger, L., Ferligoj, A., & Dorein, P. (2011). On the dynamics of national scientific systems. *Quality & Quantity*, *45*, 989–1015. doi:[10.1007/s11135-011-9484-3](https://doi.org/10.1007/s11135-011-9484-3)
- Landabaso, M., Oughton, C., & Morgan, K. (1999). Learning regions in Europe: Theory, policy and practice through the RIS experience. *Systems and policies for the global learning economy*, Westport, Connecticut and London, Praeger, 79–110.
- Lazzeroni, M. (2010). High-tech activities, system innovativeness and geographical concentration: Insights into technological districts in Italy. *European Urban and Regional Studies*, *17*, 45–63. doi:[10.1177/0969776409350795](https://doi.org/10.1177/0969776409350795)
- Lorrain, F., & White, H. (1971). Structural equivalence of individuals in social networks. *Journal of Mathematical Sociology*, *1*, 49–80. doi:[10.1080/0022250X.1971.9989788](https://doi.org/10.1080/0022250X.1971.9989788)
- Markusen, A. (1996). Sticky places in slippery space: A typology of industrial districts. *Economic Geography*, *72*, 293–313. doi:[10.2307/144402](https://doi.org/10.2307/144402)
- Martin, R., & Sunley, P. (2003). Deconstructing clusters: Chaotic concept or policy panacea? *Journal of Economic Geography*, *3*, 5–35. doi:[10.1093/jeg/3.1.5](https://doi.org/10.1093/jeg/3.1.5)
- Martin, R., & Sunley, P. (2006). Path dependence and regional economic evolution. *Journal of Economic Geography*, *6*, 395–437. doi:[10.1093/jeg/lbl012](https://doi.org/10.1093/jeg/lbl012)
- Miceli, V. (2010). *Distretti tecnologici e sistemi regionali di innovazione. Il caso italiano* [Technological districts and regional systems of innovation: The case of Italy]. Bologna: Il Mulino.
- Morgan, K. (2007). The learning region: Institutions, innovation and regional renewal. *Regional Studies*, *41*, 147–159. doi:[10.1080/00343400701232322](https://doi.org/10.1080/00343400701232322)
- Owen-Smith, J., & Powell, W. W. (2004). Knowledge networks as channels and conduits: The effects of spillovers in the Boston biotechnology community. *Organization Science*, *15*, 5–21. doi:[10.1287/orsc.1030.0054](https://doi.org/10.1287/orsc.1030.0054)
- Porter, M. E. (1998). Clusters and the new economics of competition. *Harvard Business Review*, *76*(6), 77–90. Retrieved from EBSCOhost database.
- Powell, W. W., Koput, K. W., & Smith-Doerr, L. (1996). Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology. *Administrative Science Quarterly*, *41*, 116–145. doi:[10.2307/2393988](https://doi.org/10.2307/2393988)
- Prota, L., D'Esposito, M., De Stefano, D., Giordano, G., & Vitale, M. (2013). Modeling cooperative behaviors in innovation networks: An empirical analysis. In J. C. Spohrer, L. E. Freund (Eds.), *Advances in the human side of service engineering* (pp. 369–378). Boca Raton: Taylor & Francis.
- Prota, L., & Doreian, P. (2016). Finding roles in sparse economic network: Going beyond regular equivalence. *Social Networks*, *45*, 1–17. doi:[10.1016/j.socnet.2015.10.005](https://doi.org/10.1016/j.socnet.2015.10.005)
- Prota, L., & Vitale, M. P. (2014). A pre-specified blockmodeling to analyze structural dynamics in innovation networks. In D. Vicari, A. Okada, G. Ragozini, & C. Weihs (Eds.), *Analysis and modeling of complex data in behavioural and social sciences* (pp. 221–230). Heidelberg: Springer.
- Provan, G. K., Fish, A., & Sydow, J. (2007). Interorganizational networks at the network level: A review of the empirical literature on whole networks. *Journal of Management*, *33*, 479–516. doi:[10.1177/0149206307302554](https://doi.org/10.1177/0149206307302554)
- Provan, K. G., & Kenis, P. (2008). Modes of network governance: Structure, management, and effectiveness. *Journal of Public Administration Research and Theory*, *18*, 229–252. doi:[10.1093/jopart/mum015](https://doi.org/10.1093/jopart/mum015)
- Tödtling, F., & Trippel, M. (2005). One size fits all? Towards a differentiated regional innovation policy approach. *Research Policy*, *34*, 1203–1219. doi:[10.1016/j.respol.2005.01.018](https://doi.org/10.1016/j.respol.2005.01.018)

- Tsai, W. (2001). Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance. *Academy of Management Journal*, 44, 996–1004. doi:[10.2307/3069443](https://doi.org/10.2307/3069443)
- Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge, UK: University Press.

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