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Scientific collaboration of researchers and organizations: a two-level blockmodeling approach

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Abstract
The development and successful implementation of R&D policies depends on understanding patterns of scientific collaboration (SC). Existing studies on SC typically focus on the individual level, despite SC occurring on many interdependent social levels. Therefore, this paper provides a simultaneous insight into SC patterns among researchers (individual level) and among organizations (organizational level) in the social sciences. SC on the individual level is operationalized by co-authorship of a scientific paper whereas two organizations are said to collaborate if they share a research project. Based on data for the period 2006–2015 retrieved from Slovenian national information systems, two-level collaboration networks were formed with respect to researchers in the social sciences field. These networks were analyzed using a k-means-based blockmodeling approach for linked networks. The results show a high level of interdisciplinary SC and a large organizational impact on individual collaborations. On the individual level, a structure with several cohesive clusters and a semi-periphery appears while, on the organizational level, a kind a core–periphery structure emerges in which both the core and periphery can be split into several clusters. The most surprising result indicates that SC on the level of organizations is often not reflected in common published scientific papers on the individual level (and vice versa).

Keywords Social networks · Scientific collaboration · Multilevel networks · Co-authorship networks · Blockmodeling

Introduction

In contemporary science, the interactions among scientists and their scientific collaboration (SC) are crucial processes entailed in knowledge sharing, developing human creativity, and creating novel ideas; namely, prerequisites for social and scientific innovations. SC

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can be observed from different perspectives and this diversity contributes to the abundance of various terminologies, research approaches, and methodologies. SC may be defined and classified in several ways since, according to e.g. the units of the analysis given, the actors which are represented by nodes, the type of information used to develop the links between nodes, this might consist of interactions or information (Rogers et al. 2001; Shrum and Mullins 1988).

While one can find many definitions and classifications of SC, two elements are common to them all: working together for a common goal, and sharing knowledge (Hara et al. 2003; Sonnenwald 2007).

Several studies establish a strong relationship between collaboration and the quality of the research as well as between collaboration and the speed of diffusing scientific knowledge (Abbasi et al. 2011a; Frenken et al. 2005; Hollis 2001; Katerndahl 2012; Lee and Bozeman 2005). Beaver (2004) states that collaborative research holds greater epistemic authority than research performed by individual scientists alone, making understanding the patterns involved in SC fundamental for developing and successfully implementing R&D policies.

When comes to measuring SC, Katz and Martin (1997) argued that the borderlines of scientific collaboration are unclear and there is no accurate way of measuring SC. However, while SC manifests in various forms, not all of which are visible in formal communication channels (Laudel 2002; Price and Beaver 1966), SC on the individual level is usually operationalized and studied by co-authorship, one of the most formal expressions of SC (Groboljsek et al. 2014). While studying SC on the organizational level, researchers have defined SC between organizations through co-authorship networks (Abbasi et al. 2011b; Gazni et al. 2012; Larivière et al. 2006; Thijs and Glänzel 2010) and collaboration on joint research projects (Almendral et al. 2007; Garas and Argyrakis 2008).

In this time of modern science characterized as “big science” (de Solla Price 1963), it is expected that SC on the individual level (often measured by co-authorship publications) is embedded in the context of SC on the organizational level (they are usually operationalized by collaboration on joint research projects). This assumption suggests that voluntary collaborations among independent researchers as ‘freelances’ are more the exception than the rule. It could be said that in modern science the basic unit of scientific research is not an individual, but scientific teams and scientific organizations. Collaboration between scientific institutions is based more on organizational and bureaucratic structures when it comes to the multi-institutional realization of common research goals.

Recently, the sociology of science and social network theories have oriented their research attention to institutional forms of SC, involving, e.g., an intricate division of labor and infrastructure in common research projects, formal rules or procedures for achieving research goals and greater centralization of the R&D management (Hackett et al. 2016; Shrum et al. 2007; Whitley and Glaeser 2007). Since institutional SC tends to be a central point in national R&D policy decision-making processes, it is becoming very important that scientific institutions are able to ensure that the motivation of individual scientists is in harmony with collaborating according to the requirements of national funding agencies and R&D policy decision-makers. Namely, researchers’ individual motivations and practices are not completely independent of the wider institutional policy frameworks that determine the extent and possibilities of SC (Mali et al. 2018). This broader policy and institutional framework at the macro or meso level consciously or unconsciously influences the decisions of individual researchers to build collaboration networks (e.g., to publish articles together with others). But the converse also applies—the most successful R&D policy measures for SC are usually accepted if they motivate scientists at the individual level.

While many attempts have been made to theoretically conceptualize and empirically explore both dimensions of SC (i.e., individual and institutional), efforts to capture them together have been rarer, although such an approach could assist in understanding how individual researchers might benefit from the position their organizations hold in the institutional network. This is based on the fact that exchanging resources (e.g., knowledge) on the individual level (among individuals from different organizations) affects how resources (e.g., finance) are exchanged on the organizational level (Barbillon et al. 2016; Lazega et al. 2008). Using empirical multilevel data, Barbillon et al. (2016) showed that collaboration between organizations increases the probability of collaboration between researchers and that sharing advice among researchers raises the probability that resources will be exchanged between these organizations. On the other hand, by using a truly multilevel approach, Žiberna and Lazega (2016) observed that the ties among laboratories (especially for the most active laboratories) can perhaps compensate for ties among researchers, thereby allowing researchers to become more productive by spending less time on managing their networks.

Previous studies also found a higher level of inter-institutional collaborations in the natural sciences and engineering compared to the social sciences and the humanities (Abbasi et al. 2011b; Gazni et al. 2012; Larivière et al. 2006). This is expected since, generally speaking, scientific problems are (in the natural sciences and engineering) usually solved only with the help of expensive instruments, laboratory facilities, technical services, etc. Although it would be a simplification to present the cognitive and organizational structures of the social sciences and humanities on one hand and natural sciences and engineering on the other in a bipolar manner, certain key differences between them can be observed. For example, the progress of certain disciplines in the natural sciences and engineering requires research instruments that exceed the ordinary finance sources due to their size and cost. Such a situation could act as a strong motivator for multi-organizational forms of collaboration at the national and transnational levels. For that reason, scientific institutions in the natural and engineering sciences are more often obliged to mobilize organizational and bureaucratic structures of collaboration like in the social sciences and the humanities. But, as mentioned, modern science is no longer based on any rigid division between the 'soft' and the 'hard' sciences. In all fields of modern science, voluntary collaborations among independent researchers (in the form of freelancing) which are not embedded in institutional and organizational structures are harder to establish and maintain. For instance, a transformation from Mode 1 Science to Mode 2 Science has been underway in recent times. In Mode 2 Science, new forms of knowledge production are replacing mono-disciplinary and individual research practices with interdisciplinary, transdisciplinary, and organized collective research practices. These new ways of producing scientific knowledge have encouraged various forms of SC.

In Slovenia, several studies considered SC on the individual level (Karlovčec and Mladenić 2015; Kronegger et al. 2012; Mali et al. 2010, 2012; Perc 2010). One of the first to consider Slovenian SC networks was done by Ferligoj and Kronegger (2009). They analyzed the co-authorship network of Slovenian sociologists registered in 2008 at the Slovenian Research Agency (ARRS). Applying a blockmodeling approach, they identified a clear multi-core–semi-periphery–periphery structure. Here, the term multi-core refers to several clusters of researchers who are internally well linked with each other while researchers from different clusters have fewer links connecting them. Semi-periphery refers to a cluster of researchers who collaborate with the others less systematically while periphery refers to a cluster of researchers who published at least one scientific publication, but not in co-authorship with other studied researchers. This structure was later confirmed to exist in most scientific disciplines (Cugmas et al. 2016; Kronegger et al. 2011).[1]

Regarding the R&D science policy context of SC in Slovenia, the existing studies mentioned above show that SC among researchers are still not properly supported and rewarded. For example, several studies reveal many deficiencies in use of the R&D evaluation system (Mali 2013; Mali et al. 2017). Still, the situation changed radically after the political turn at the beginning of the 1990s. The reorganization of R&D policies after this political turn brought many changes to Slovenia as well. In this regard, the situation was similar to other Central and Eastern European countries at the time (Pálné and Kusar 2010). Concerning the introduction of more modern forms of R&D policy in Slovenia, an important landmark is the establishment of the public research funding agency, ARRS. In 2000, ARRS took over the role of distributing funding across the public research sector (universities, public institutes). This meant ARRS holds an exclusive role in funding public research in Slovenia (Demšar and Boh 2008; Mali 2013). At the operational level, ARRS is directly responsible for evaluating and financing various types of research project proposals. It is interesting that ARRS introduced a new condition for financing research project proposals submitted for evaluation in the context of a public tender which had been absent prior to the reorganization of R&D policy, i.e. collaboration among research institutions is required. This means that before the whole procedure of R&D evaluation organized by ARRS research institutions in Slovenia applying for the financing of a research project must prepare a very detailed plan of inter-institutional SC. For example, annual public invitations from 2008 onwards issued by ARRS for applications to finance research projects define the formal criteria each research institution applying (in the role of principle investigator) for financial support for a proposed project must attract at least one additional participating research institution that aims to perform at least 20% of the project value (e.g., Uradni list 2008). The research institution submitting the proposal need to give all relevant information about the proposed inter-institutional collaboration (there are no limits on the number of participating research institutions) to the ARRS administration. It is expected by R&D policy decision-makers in Slovenia that the new way of organizing R&D activities in the form of projects and the introduction of a formal inter-institutional SC requirement will benefit both the nature of scientific inquiry and the general production of scientific knowledge in Slovenia.

The aim of this study is to give simultaneous insights into patterns of SC among individual researchers (individual level) and among research organizations (organizational level) in the social sciences, a well-established scientific field in Slovenia with a developed research culture and established research organizations.[2] More specifically, the global network structure on both levels is to be identified as well as how scientific field affects SC and how organizational level affects SC among individual researchers. Here, SC on

[1] The multi-core–semi-periphery–periphery structure was not found only in Slovenia, but also in other counties, i.e., within teaching staff at the Faculty of Humanities and Education Science's Departmenr of Library Science at National University of La Plata in Argentina (Chinchilla-Rodríguez et al. 2012).

[2] Although for the period before political turn in 1990 was characterized by periodical political interferences in the social sciences in Slovenia, the processes of professional autonomy and identity of social scientific disciplines started already in the former one-party political regime. The social scientists early began promoting empirical research rather than just follow official ideology. They introduced many new inquiry objects, branches and disciplines, and carefully cultivated their professional profiles (Kramberger and Mali 2010). The political turn in 1990 certainly improved the position of social sciences in Slovenia concerning their endeavours for a stronger autonomy, a higher professional status and internationalization of research.

the individual level will be operationalized by co-authorship of a scientific paper while two institutions are said to collaborate if they collaborate on a joint research project. Common projects are important indicators of institutional R&D collaboration because they represent the formulation stage in which researchers initiate and plan their collaborative research projects. After the initial plan for collaboration is designed and the work begins, it is strongly expected that such collaboration will be sustained over a certain period of time to achieve the research goals.

The paper is structured into several parts. First, the data sources and the methodology, including the blockmodeling approach used to reveal the global structure of SCs, are described following with a presentation of the blockmodels obtained with different numbers of clusters. The results are interpreted in light of the R&D policies in Slovenia in the conclusion.

Data and methodology

The data source and analyzed data are described below, followed by a description of the methodology applied.

Data

The data sources are the Co-operative Online Bibliographic System and Services (COBISS) (maintained by the Institute of Information Science) and the Slovenian Current Research Information System (SICRIS) (maintained by the Institute of Information Science and ARRS). The data sources are unique in an international context because they encompass information on Slovenian researchers, research organizations, and research projects. The data are available for all entities (i.e., researchers, organizations and research projects) that are fully or partially financed by ARRS and other entities, which submit their data voluntarily.

SICRIS contains data about researchers (including their affiliation and field of research), research organizations (including their primary field of research and involvement in national and international research projects), national and international research projects, and other data on scientific activities in Slovenia.

Data for the 10-year period between (including) 2006 and (including) 2015 are analyzed. Only researchers from the social sciences who published at least one scientific paper are considered. There are 788 such researchers from various scientific disciplines, mostly the scientific disciplines Economics (256 researchers or 33.6% of all researchers) and Educational Studies (135 researchers or 17.1% of all researchers) (Table 1). These researchers were employed at 64 distinct organizations (e.g., faculties, institutes, …) with different fields of research (see Online Resource), not only the social sciences (which accounts for 61% of all organizations) (Table 2). Since there are only a few organizations engaged in certain scientific disciplines, they are grouped by the ARRS classification scheme of scientific fields, disciplines, and sub-disciplines.

Connecting SICRIS and COBISS allows the formation of complete personal bibliographies of all researchers ever registered with ARRS. Different types of scientific publications may be considered while constructing researchers' personal bibliographies. In this study, original scientific article (9987 items), review article (1428 items), and short scientific article (304 items) are considered.

Table 1 Number of researchers from the social sciences by scientific discipline with at least one scientific paper published between 2006 and 2015

Discipline	No. of researchers	%
Economics	256	33.6
Educational studies	135	17.1
Administrative and organizational sciences	91	11.5
Sociology	74	9.4
Psychology	58	7.4
Political science	47	6.0
Sport	34	4.3
Criminology and social work	25	3.2
Law	23	2.9
Urbanism	13	1.6
Information science and librarianship	13	1.6
Architecture and design	9	1.1
Ethnic studies	1	0.1
Total	788	100

Table 2 Number of organizations by field of research

Scientific fields and disciplines	#	%	Grouped scientific disciplines	#	%
Natural sciences and mathematics[a]	5	7.8	Natural and biotechnical sciences	8	12.5
Mathematics	1	1.6			
Computer-intensive methods and applications	1	1.6			
Biotechnical sciences[a]	1	1.6			
Civil engineering	3	4.7	Engineering sciences and technologies	9	14.1
Energy engineering	2	3.1			
Systems and cybernetics	1	1.6			
Computer sciences and informatics	1	1.6			
Manufacturing technologies and systems	1	1.6			
Traffic systems	1	1.6			
Medical sciences[a]	5	7.8	Medical sciences	6	9.4
Microbiology and immunology	1	1.6			
Social sciences[a]	10	15.6	General social sciences	10	15.6
Economics	13	20.3	Economics	13	20.3
Educational studies	4	6.2	Other social sciences	16	25.0
Sociology	2	3.1			
Administrative and organizational sciences	2	3.1			
Law	3	4.7			
Criminology and social work	2	3.1			
Psychology	1	1.6			
Architecture and design	2	3.1			
Humanities[a]	2	3.1	Humanities	2	3.1
Total	64	100		64	100

[a]Scientific field (others are scientific disciplines)

Two-level networks are constructed using these data. One level (individual level) is about scientific collaboration among researchers while the other (organizational level) concerns scientific collaboration among organizations. The nodes on the individual level represent researchers who published at least one scientific paper between 2006 and 2015. Two researchers are linked if they co-wrote at least one scientific paper.

While scientific collaboration among researchers is operationalized by co-authorship, collaboration among organizations is operationalized by a joint project (the nodes on the organizational level are organizations). In total, 3367 national and international research projects are considered (Table 3). A given research organization is included in the network if it employed at least one researcher from the individual network level.

The nodes in the two-mode network are individuals and organizations. A link exists between a researcher and an organization if the researcher is employed by the organization. Each researcher is employed at a single research organization,[3] yet there are no data on organizational affiliation for some researchers (215 researchers or 27.3% or all researchers), possibly because they were already retired or working at an organization without an ARRS ID.

Methodology

The network data are analyzed using the blockmodeling approach. The blockmodeling analysis in this study can be seen as a relatively rough description of a multilevel network, in some sense similar to looking at the histogram of a univariate variable. However, such explorative methods can give useful insights into the data and suggest interesting hypotheses or research questions for further analysis, as were also provided in this analysis. More specifically, in a blockmodel, groups of equivalent (according to the structure of their links) nodes from the empirical network are reduced to transform large, complex, and potentially incoherent networks into smaller and more comprehensible networks (Doreian et al. 2005). The relationships between the clusters so obtained can serve to operationalize social roles (Borgatti and Everett 1992).

Several approaches can be found for blockmodeling. In this study, the k-means-based blockmodeling approach for linked networks is used (Žiberna 2020). It enables different levels of multi-level networks to be simultaneously blockmodeled and is considerably faster (hence suitable for larger networks) than generalized blockmodeling for multilevel networks (Žiberna 2014; Žiberna and Lazega 2016). Considering two levels is one way in which this study differs from those done by Kronegger et al. (2011) and Cugmas et al. (2016) while another difference is that the method for blockmodeling used in the former studies is optimized to finding quite small but tightly linked clusters of nodes while the k-means approach used in this study can also find larger and less tightly linked clusters of researchers. This is especially relevant while analyzing very large networks (e.g., as at the level of scientific fields) where the primary interest is not in small tightly linked clusters of researchers and/or organizations, but in larger, not so tightly but equivalently linked clusters of researchers and/or organizations. When using the k-means approach, the groups that are obtained are also less affected by single authorships (between researchers) or research projects (between organizations).

[3] If a researcher is assigned to more than one organization in the database, then an organization to which he or she jointed more recently is considered.

Table 3 The types and the number of the research projects considered

Project type	Short description	Number of projects
Basic	Covering experimental or theoretical research undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts	673
Target	Representing a system created in 2001 for inter-sectoral cooperation in planning and implementing networked R&D projects for specific areas of public interest	605
Applied	Representing an original investigation undertaken in order to acquire new knowledge; directed towards a specific practical aim or objective	392
Postdoctoral	Basic or applied research projects carried out by one researcher (no more than 3 years after obtaining a doctorate)	158
International	European and other international research projects	1539
Total no. of projects		3367

Simulation studies reveal that different network levels can have a disproportionally large impact on the blockmodeling solution when their sizes considerably differ. Therefore, different parts of the network were weighted inversely proportional to the number of errors that would have been obtained had each part consisted of just one block (Žiberna 2014). Since, after using such weights, the two-mode part of the network was partitioned with considerably fewer errors than the other parts, the weights for the two-mode part were further divided by two, resulting in the following weights: 1.000 for the individual level, 4.674 for the organizational level, and 3.098 for the two-mode part of the network.

Selecting the number of clusters is harder in the case of multi-level blockmodeling because a user must select the number of clusters for each level, which can result in many possible solutions. In this paper, the number of clusters was chosen based on the values of a criterion function, calculated for a different number of clusters (see Online Resource). The number of clusters was chosen based on the shape changes of the criterion function value which, to some extent, is subjective. For deeper insight into the structure of scientific collaborations, three solutions were chosen: a solution with a small number of clusters (5 clusters of individuals and 3 clusters of organizations), a solution with an intermediate number of clusters (15 clusters of individuals and 6 clusters of organizations), and a solution with a high number of clusters (22 clusters of individuals and 8 clusters of researchers). The results are presented below.

Results

The multilevel results for the individual level, the organizational level, and the two-mode network connecting them are interpreted in the following sections.

Blockmodeling solutions

The blockmodels are visualized by graphs (see Online Resource for two-level networks in matrix form drawn in line with the blockmodeling solutions). Nodes marked with the letter “O” (red-colored nodes) represent clusters of organizations whereas nodes with the letter “R” (blue-colored nodes) represent clusters of individuals. The nodes’ sizes for individuals are in proportion to the number of researchers in each cluster while the nodes’ sizes of organizations are in proportion to the total number of researchers from organizations belonging to a given cluster.

The widths and color intensity of the edges within individuals and within organizations are proportional to the density of the blocks that connect two given clusters of individuals or organizations. The widths and color intensity of the edges between clusters of individuals and clusters of organizations are arranged to represent a share of individuals from a given cluster of individuals who affiliate with a given cluster of organizations.

The nodes are drawn as pie charts to indicate the diversity of the scientific fields of work engaged in by the individuals and organizations.

Small number of clusters

The chosen solution with a small number of clusters entails five clusters of individuals and three clusters of organizations. The solution is visualized in Fig. 1.

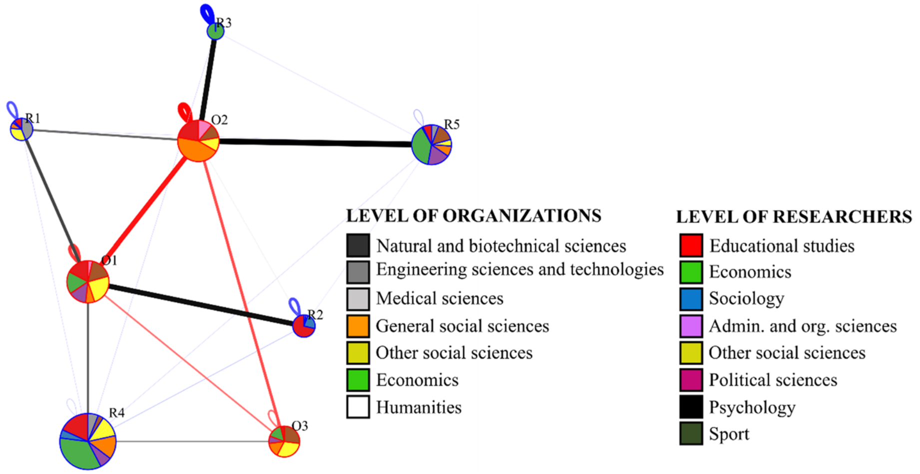

Fig. 1 Visualization of the blockmodeling solution in graph form for the solution with five clusters of individuals and three clusters of organizations

The network on the individual level has a global structure with several cohesive groups and a semi-periphery while the structure of the organizational network-level comprises one core cluster of organizations and two peripheral clusters, of which one (O1) is more strongly linked with the core cluster than the other (O3).

The core cluster of organizations (O2) mainly consists of the key Slovenian faculties operating in the social sciences. The first peripheral cluster (O1) comprises other organizations, mostly faculties (and the National School for Leadership in Education, the National Institute of Public Health, and the University Medical Center Ljubljana) and the second peripheral cluster (O3) consists of other organizations and institutes (including some faculties). The latter organizations are not so strongly linked to each other which may be because they collaborate more with organizations from other fields.

Going back to the individual level, the first cluster of researchers (R1) largely consists of researchers from the scientific disciplines Psychology, Criminology, and Social Work. These researchers are affiliated with organizations from the first peripheral cluster of organizations and the organizations from the core cluster of organizations. R2 and R3 are to some extent specific since most researchers from R2 are employed by the Faculty of Sport, University of Ljubljana (UL) (from the scientific disciplines Sport and Educational Studies) while almost all researchers in R3 are employed by the School of Economics and Business (UL). The last core cluster (R5) contains the highest number of researchers among the core clusters and is very mixed regarding research fields, but all the researchers are employed by organizations in the core cluster of organizations.

The semi-periphery (R4, the cluster with the most researchers) also consists of researchers from various scientific disciplines, although their affiliation is with peripheral organizations.

To summarize, the structure of the network on the individual level has several cohesive groups of researchers and a semi-periphery, while the structure corresponding to the organizational level is close to a core–periphery one. Interestingly, the strongest connection between clusters on the organizational level is not based on connected clusters of researchers (where each cluster is connected to one organizational cluster) but

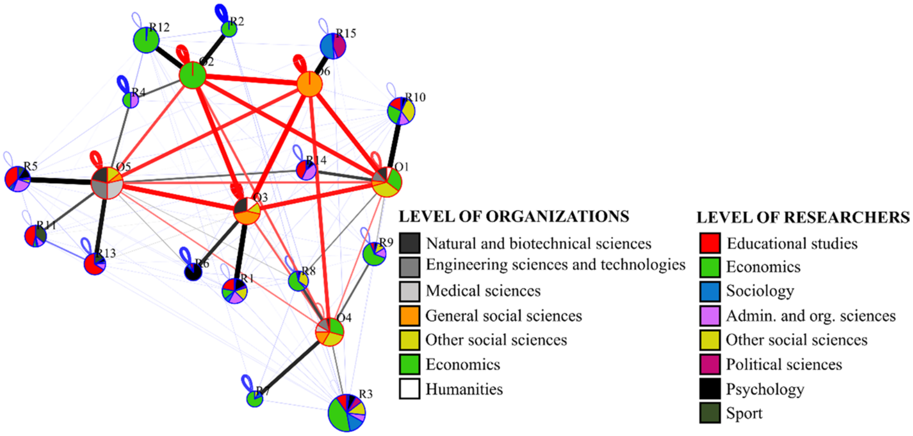

Fig. 2 Visualization of the blockmodeling solution in graph form for the solution with 15 clusters of individuals and 6 clusters of organizations

on the researchers' clusters which are connected (associated) with several organizational clusters.

Intermediate number of clusters

For the case of an intermediate number of clusters, 15 clusters of individuals and 6 clusters of organizations were specified. A detailed description of the global network structure obtained is found in Online Resource. The solution is visualized in Fig. 2.

The global structure of SC on the individual level entails several cohesive clusters of researchers which are generally not strongly linked with each other. More strongly linked than others are the clusters R11 and R13, which form a core–periphery structure (R13 as core, R11 as periphery).

The clusters of organizations are generally well linked to each other. The exceptions are O4 (different faculties and institutes in the social sciences) and to a smaller extent O5 (a high number of health-related organizations and organizations from the natural sciences). Organizations within clusters O1 and O4 are less strongly linked, possibly due to the relatively large number of organizations in these clusters. Cluster O2 consists of only the School of Economics and Business (UL) and cluster O6 contains only the Faculty of Social Sciences (UL).

It is unusual that several clusters of individuals have few links despite their affiliated organizations being well linked with each other (especially when one of the clusters is O2 or O6). One explanation may be that the results of a joint project were not published in the form of a scientific paper, while another may be that these research organizations are not as strongly linked to each other as first seems. This is because it is easier for a single organization—compared to a cluster of several organizations—to collaborate with most organizations from a cluster of several organizations.

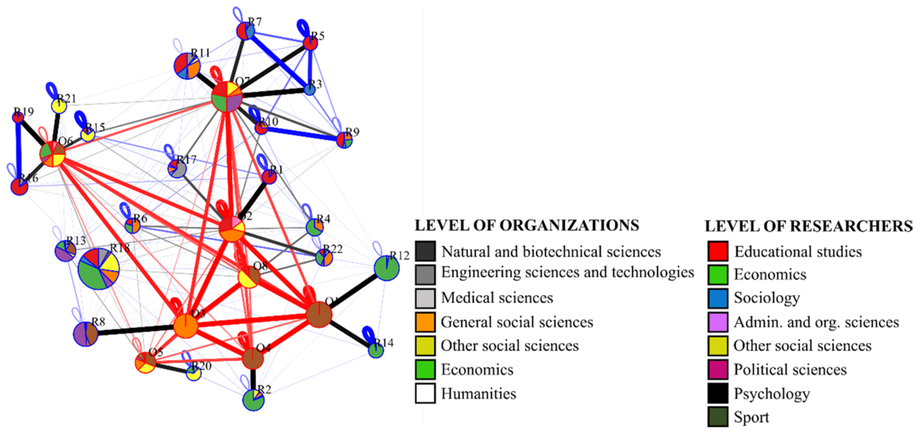

Fig. 3 Visualization of the blockmodeling solution in graph form for the solution with 22 clusters of individuals and 8 clusters of organizations

High number of clusters

The blockmodeling solution with 22 clusters of individuals and 8 clusters of organizations is interpreted in this subsection. A more detailed description of this structure is provided in Online Resource, while a general overview is presented below (the solution is visualized in Fig. 3).

The cohesive clusters obtained on the individual level are generally more linked with each other compared to the solutions obtained when using a small and intermediate number of clusters. Like for the previous solutions, one finds clusters of researchers that are highly determined by their organizations (e.g., R1, R6, R7, R8). When a cluster of organizations is made up of only one organization: (1) most corresponding researchers are clustered in a single cluster (e.g., R2 and R8); (2) the researchers are clustered into generally non-linked clusters (e.g., R12 and R14); or (3) the core–periphery structure appears between clusters of researchers (e.g., R5 and R7, R9 and R10). A cluster with a relatively high number of researchers also exists (R18). These researchers from many different scientific disciplines are peripheral, reflected by the fact that they are less linked to all other clusters of researchers and that they belong to organizations from different clusters.

On the organizational level, five clusters (O2, O5, O6, O7, O8) consist of several organizations and three clusters (O1, O3, O4) have one organization within each. The latter are organizations with a very large number of researchers. O5 is also a cluster of organizations that are generally less linked to any other organization. This cluster comprises various institutes and some smaller faculties. For many of them, the social sciences is either not their primary research field or they are not members of the university.

Clusters of organizations O1 (School of Economics and Business, UL), O2 (mainly organizations associated with the coastal region of Slovenia), O3 (Faculty of Social Sciences, UL), and O8 (organizations related to law or economic studies) are cohesive and well linked with each other. By considering the structure of the network, these clusters represent the core institutions of Slovenian social sciences research. The remaining clusters may be regarded as more peripheral. They are connected to the core, but not (at least strongly) with each other. Clusters O5 and O6 (both different institutes and faculties from various fields) are also not cohesive, although the rest are, namely, cluster O7 (different faculties from the natural and technical sciences and medicine) and cluster O4 [Faculty of Business and Management, University of Maribor (UM)].

Discussion

It is vital to consider the different social levels on which SC operates to understand the mechanisms that underlie such collaborations and thereby develop effective R&D policies. Therefore, the structure of SC was studied in this paper by jointly analyzing the co-authorship network on the individual level and joint project collaboration on the organizational level. The relationship between these two levels was also taken into account.

The multi-level network was analyzed by using the k-means blockmodeling approach for multi-level networks. Blockmodeling was used as an exploratory technique. The goal of such analysis is therefore to answer specific questions, but more to gain an initial impression about a certain subject (the multilevel nature of scientific collaboration in Slovenia in this case) and formulating research questions or hypotheses. As the desired "resolution" is not known in advance, blockmodeling solutions with different numbers of clusters was explored.

Individual level

The global network structure observed on the individual level is similar to that found by Kronegger et al. (2011) and Cugmas et al. (2016): the clusters of researchers are generally well separated (well-separated clusters of researchers also emerge within certain individual organizations), meaning that the researchers in different clusters do not tend to collaborate.[4] Although they collaborate with other researchers in a less systematic way, researchers who are not part of closely linked (cohesive) clusters were found in all studies. This is the case even though the analyses of SC are made on the level of scientific field instead of scientific disciplines (as was done by Kronegger et al. (2011) and Cugmas et al. (2016)), which mitigates the limitations related to the network boundaries.

By also considering the organizational level in the current study, a better insight into the relationship among SC on different levels could be obtained. The most general observation is that SC on the individual level is largely determined by the researchers' organizational affiliations while there is still a high level of interdisciplinary collaboration (also see Online Resource).

Organizational level

The network of collaborations on the organizational level is relatively dense, indicating that different organizations tend to collaborate. A kind of a core–periphery structure emerges in which both the core and periphery can be split into several clusters. The results of the current analysis show that the structure of the clusters on the organizational level is

[4] Exceptions were found in all studies either in the form of core–periphery structures or as a presence of bridging cores (i.e., clusters of researchers that collaborate with two other clusters of researchers, which do not collaborate).

determined by several factors, namely the size of the organizations (some organizations with a very high number of researchers are in their own clusters), their geographical position (e.g., some clusters mainly consist of organizations located entirely or partly in the coastal region of Slovenia), and their type (some clusters consist of organizations whose primary activity is not research).

Smaller organizations and organizations whose primary activity is not research are found in a cluster of organizations that are generally less linked (both within the clusters and with other clusters). The central organizations in the social sciences, which mainly include large social science institutions, collaborate with most of the other organizations under study and may be seen as core organizations also in the context of the global network structure.

The denseness of the network among organizations is not only a consequence of the need for interdisciplinary collaboration or the need for access to different scientific infrastructures since it also reflects the fact that interorganizational collaboration in a small scientific community can bring disproportionally greater international advantages. For example, recent European Union R&D collaborations tend to be based on the complexity and diversity of partners to be involved in common consortia, their varied geographical, and institutional origins, etc. This means that research groups from different EU member states working in an EU R&D context are faced with a complex and changing environment which forces them to integrate and concentrate their R&D efforts at the national level already before entering into consortiums of partners (Barber et al. 2011; Kim and Bak 2017). Therefore, the concentration of R&D potential at the national level through any kind of more formal and institutionalized SC is positive, provided, of course, that this concentration does not produce the negative consequences of the "agglomeration effect" (i.e., the probability of finding a potential collaborator at the international level is higher in a country that has many scientists than in a country with fewer scientists). Still, even countries with very large R&D human resources are sometimes forced to join their R&D efforts at the national level before they enter the demanding area of international R&D competition.

When considering the factors of largeness and geographical position, with respect to the first factor it is necessary to look back into the history of the origin and development of the social sciences in Slovenia. The Faculty of Social Sciences, the Faculty of Economics and a few other faculties at the University of Ljubljana were the exclusive (institutional) source of scientific knowledge in the field of the social sciences in Slovenia. Considering the country's smallness, they have retained their position as big social science centers for the whole period, although after the political turn in 1990 some geographical proliferation of the university system was seen (e.g., the emergence of social science institutions at the newly established University of Koper and the University of Nova Gorica). It seems that an academic institution's size is also an attractive factor in the case of SC, although size in science by itself does not guarantee quality research output.

Two hypotheses can be formed regarding the existence of a cluster of organizations from the same geographical region in Slovenia. The first is that the cluster emerged as a realization of the "agglomeration effect" that is leading to a pronounced regional orientation of social science institutions to support the building of a new innovation system on the Slovenian coast,[5] while the other is that this cluster emerged due to the parochiality and

[5] In innovation theories and practices, regional innovation systems are on the same way as national innovation systems formed by multiple actors (firms, higher education institutions, research and technological centers, local policy decision makers etc.) interacting and giving rise to learning processes and innovations (González-López and Asheim 2020).

lack of transnational openness of social science institutions in this part of Slovenia. Future research could address the proposed hypotheses by examining the transnational patterns of SC on the individual and institutional levels. In any case, in our view, a too strong spatial concentration of institutional R&D structures does not provide comparative advantages for Slovenia. Comparative advantages would only flow from embedding this R&D potential in a very flexible and dynamic innovative environment.

Multilevel aspect

The most unexpected and surprising finding of this study is that the ties between the clusters of organizations (i.e., ties based on joint projects) are generally not supported by the ties between the clusters of individuals. In some cases, these ties connecting clusters of organizations are 'supported' by researchers from linked clusters that are part of the same clusters of individuals. These might be either the cause or the result of organizational ties. This indicates that inter-organizational projects are either the cause or the consequence (a temporal analysis is needed to distinguish) of researchers' collaboration clusters.

Can the results of our empirical analysis lead to the conclusion that the mandatory requirements introduced by ARRS to build SC among research institutions have not in fact contributed much to the excellence and productivity of scientific inquiry and, generally speaking, to the production of scientific knowledge in Slovenia at large? Such a conclusion would be an exaggeration. A much more detailed and targeted empirical analysis is needed to answer all of the detailed questions entailed. Still, the relatively large incompatibility between the ties on the individual level and the ties on organizational level indicates that the social sciences in Slovenia are still to some extent characterized by the old-fashioned way of operating. In old-fashioned models for the social sciences, SC is chiefly based on the spontaneous and contingent "free will" of individual researchers to engage or not engage in professional SC with their colleagues. As noted by many sociologists of science, the modern social sciences are no longer based on the little "romantic" model of "lonely seekers after scientific truth" (Ziman 2002, p. 70). Today, social science research, almost by the definition, requires greater compatibility between the 'free will' of individual researchers and the 'organized efforts' of R&D policy actors. Namely, the traditional definition of autonomy (as self-governing or self-ruling, not limited by R&D policy goals) is no longer adequate. It seems that the field of the social sciences in Slovenia has yet to accomplish the optimal synergy of spontaneous and organized/institutionalized forms of SC.

Limitations and future work

Several questions or possibilities for improvement are indicted above. For example, it is noted that the network of organizations is very dense and, thus, the different clusters of organizations obtained are very closely linked. Therefore, considering weights on the links between organizations (i.e., the number of joint projects) could lead to more detailed insights into the structure of SC among organizations. However, this would touch on several unsettled questions. The best way of measuring the intensity of SC among organizations is still unknown. This is a very complex topic that has no unique solution, even on the level of individuals where much greater progress has been made (which might also be relevant to the level of organizations) (Batagelj 2020). In addition, blockmodeling valued networks on a single level is also a very complex topic per se (Nordlund and Žiberna 2020), while it becomes even more complex to apply this approach to a multilevel situation.

The most important question is why the ties among the clusters on the organizational level are generally not well supported by the ties among the clusters on the individual level, especially as this might indicate that the policy of promoting the participation of several organizations in research projects is not leading to much SC on the individual level. However, as mentioned, blockmodeling analysis is not designed to answer such questions. Several approaches might be considered to answer such questions. One would be to look for the overlap between the network of co-authorship and indirect ties among authors through their institutions, like in Lazega et al. (2008, 2013). Another approach would be to analyze the multilevel network by using multilevel Exponential Random Graph Modeling (Wang et al. 2013, 2016) or Stochastic Actor-Oriented Models (Snijders 2017), where one can test whether a link on one level increases the probability of a link on the other level. Yet, probably the most direct approach is the most appropriate, namely, where one could (for each project that includes multiple institutions) check the co-authorship networks based on publications produced by the project (where this information is available) or simply among all project participants for some reasonable time period. Based on these co-authorship networks, it would be possible to assess how many co-authorships cross over organization boundaries and perhaps compare this to either single-organization projects or pre-project co-authorship networks.

Since this is one of the first analyses in which two levels of SC are studied simultaneously by using blockmodeling, several limitations are worth noting: (1) only the presence or absence of ties was considered. For a more thorough and reliable analysis, different operationalizations of SC should be considered on both levels. This includes reconsidering how SC is operationalized (especially on the organizational level) and how the values on the ties are determined; (2) only social science researchers (and their institutions) were considered. Considering other scientific fields would allow a more thorough analysis since one shortcoming of this analysis is that collaboration with other scientists is excluded; (3) only a 'static' analysis is performed. Temporal analyses would enable a more profound insight into how the structure of SC evolves.

Conclusion

The aim of the paper was to study the structure of the scientific collaboration (SC) of Slovenian researchers and organizations in the field of Sociology. To this end, the blockmodeling approach was used in an exploratory manner. The main finding is that the ties among clusters of organizations are often not reflected in ties among the clusters of researchers affiliated with them. That might indicate that SC on the level of organizations is often not reflected in common published scientific papers on the individual level (and vice versa). Further, this could mean that the policy implemented by the Slovenian Research Agency that up until recently required at least two organizations to participate in national projects has been unsuccessful in in increasing inter-organizational SC at the level of researchers. Based on these results, several possible approaches are suggested for further research to examine whether this is indeed the case by analyzing within-project co-authorship networks and also to provide deeper insights into such networks.

Another important finding is that the clusters of researchers obtained are very mixed in terms of disciplinary affiliations, indicating relatively high interdisciplinary SC. Moreover, many clusters of researchers consist of researchers from the same cluster of organizations, suggesting that organizational affiliation has a big impact on SC on the individual level (especially when the cluster of organizations contains one organization only). The Discussion section also mentioned possible directions of further research based on these results.

The results confirm that simultaneously studying SC on multiple social levels is necessary to understand how the structure of SC affects the structure of individual SC and vice versa.

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Author's contribution The study was conceptualized and designed by AŽ. Material preparation and data collection were the work of MC. Formal analyses were conducted by MC and AŽ. The first draft of the manuscript was written by MC and all authors commented on previous versions of the manuscript. The manuscript was edited by all authors after the first review. All authors read and approved the final manuscript.

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Data availability Data are based on publicly available data in the SICRIS and COBISS systems run by the Institute of Information Science and the Slovenian Research Agency. The data are available at http://www2.arnes.si/~aziber4/blockmodeling/SCtwoLevelKmeans/.

Code availability The two-level blockmodeling approach was applied by the "kmBlock" package for the R-programming language. The package is publicly available at https://r-forge.r-project.org/R/?group_id=203. The 0.0.1 version was used. The code is available at http://www2.arnes.si/~aziber4/blockmodeling/SCtwoLevelKmeans/.

Compliance with ethical standards

Conflict of interest The authors declare no competing interests.

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