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## Science-Nonscience Research Partnership in Poland

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**Abstract:**

**Purpose:** The objective of this paper is to inquire into the network structure of publicly financed research collaboration, which Polish scientific institutions undertake with their commercial and non-commercial partners from a multilevel perspective (international, domestic, and intra-regional one).

**Design/Methodology/Approach:** Data collected from the POL-on was used. There were identified 97 publicly financed scientific inter-organizational projects launched in 2019. Social network analysis was applied: there were recognized components, bi-components, centrality measures were calculated (degree, closeness, betweenness).

**Findings:** Polish scientific institutions conduct cross-sectoral projects at different hierarchical levels, and nearly half of them involve partners from different domestic regions. A trilateral partnership between sectors is visible within international projects, while at domestic and local levels, science collaborates with those sectors separately. Warsaw University of Technology is a dominant entity recognized within the identified network.

**Practical Implications:** The conducted analysis helped describe some effects of the public financing system of Polish science. There were also indicated entities of significant meaning within this network. Particular science sector institutions may apply the research results to their future strategies.

**Originality/Value:** This study enriches the empirical investigation on cross-sectoral research collaboration in Poland (that includes not only university-industry-government linkages but also encompasses other types of scientific, commercial, and non-commercial entities). Moreover, a multilevel perspective was applied.

**Keywords:** Research collaboration, triple helix, social network analysis.

**JEL codes:** O30, I23.

**Research Type:** Research paper.

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## 1. Introduction

The requirement for science to be networked became obvious these days. Research collaboration ensures access to specific resources such as knowledge, skills, equipment, or funds (Bammer, 2008; Bozeman and Corley, 2004) and results in greater research productivity (Abramo, D'Angelo, and Di Costa, 2009; Lee and Bozeman, 2016). The research conducted with foreign entities prevents domestic ones from scientific exclusion (Kwiek, 2018), brings the broader research perspective for investigating global social problems (Woldegiyorgis, Proctor, and de Wit, 2018), as well as rises the prestige of scientific institutions, and finally results in local and regional development (Olechnicka, Ploszaj and Celińska-Janowicz, 2018). Moreover, the triple helix concept (Leydesdorff and Etzkowitz, 1996) and its extended models (Carayannis and Campbell, 2009, 2010; Leydesdorff, 2012; Park, 2014) emphasized the necessity of cross-sectoral collaboration for knowledge creation and dissemination that fosters economic and social development.

All those advantages induce authorities (at national, regional, or even institutional level) to promote research collaboration within which science often plays a vital role but at the same time needs to be an element of a more comprehensive system. Incentives are usually financial (as often the inter-organizational or cross-sectoral collaboration is a condition for receiving a grant). Results of those endeavors have been described within elaborations about national innovation systems (NIS) and regional innovation systems (RIS) and within a transnational perspective. Works that apply to the Polish context usually focus on public statistical data (Kliniewicz and Marczewska, 2017; Łącka, 2017) or considers case studies (Bojar and Bojar, 2020; Dyba, 2016). This study enriches the empirical investigation on cross-sectoral research collaboration in Poland (that includes university-industry-government linkages and encompasses other types of scientific, commercial, and non-commercial entities) by exploring its network structure and identification of crucial network positions.

Thus, the objective of this paper is to inquire into the network structure of publicly financed research collaboration, which Polish scientific institutions undertake with their commercial and non-commercial partners from a multilevel perspective (international, domestic, and intra-regional one). Social network analysis was used to provide quite a comprehensive image of research collaboration and to answer the following research questions:

- Does the available public funding encourage Polish science to conduct research collaboration most intensively with other sectors locally, inter-regionally or internationally?
- Do those three sectors (science, commercial and non-commercial organizations) integrate within joint research partnership or whether science develop collaboration with other sectors separately?

- Which institutions show a significant position (revealed by centrality measures) within network structure? Are there any cut-vertices that create bridges between international and regional clusters of research collaboration?

## **2. Literature Review**

### **2.1 Different Sectors Within the Knowledge Production System**

The role of cross-sectoral linkages for providing the knowledge infrastructure of society and fostering economic development has been discussed widely within the last few decades. Those considerations were initiated by the emergence of the triple helix concept (Leydesdorff and Etzkowitz, 1996) that assumes interactions between three traditionally recognized spheres of knowledge-based society (university, industry, and government -UIG) as a driving force for the development of innovation system. Strengthening those mutual relations helps not only to improve primary functions of those three types of actors in innovation creation (university), implementation (industry), and integration for the public good (government) but also to compensate lacks in performing through supportive activity or even functional overlap of those institutions (Etzkowitz, 2008; Zhou, 2014). Besides creating knowledge and educating future employees, science transforms the academic knowledge into practical solutions that may be implemented within an industrial activity (technology) or utilized for the public and supports authorities with expertise in strategy formulation.

Moreover, science reveals its entrepreneurial face by launching its businesses -spin-offs. The industrial sector not only puts the knowledge products into the market but also participates in research and development projects for better adaption of scientific outputs to business practice, influences government decisions through public consultation or lobbying, as well as provides its R&D activity, finances research, and delivers public services within public-private partnerships. Even the government, apart from its regulatory function, also stimulates local entrepreneurship (tax breaks, infrastructural investments, searching for external investors), animates science-industry cooperation (through public funds programs), replaces the market processes (e.g., through determining prioritized smart specializations in regions), engages capital in new ventures (such as technology parks or development agencies), as well as promotes innovations from a particular region or city and educates the society.

However, when considering the inter-organizational cooperation of UIG within just the research activity (knowledge creation and development), we should mention conflicts that may arise because those institutional actors reveal a different approach to knowledge strategies (that stem from their core missions). Scientists insist on wide knowledge dissemination as the source of further scientific discourse; companies desire unique knowledge as the source of competitive advantage, and government focus on the utility of knowledge that is in its interest and may be used for fulfilling national or citizens' specific needs (Ponds, 2009). Those differences maybe even more

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significant within international collaboration when partners do not share the same norms and values, operate in different legal frameworks, and are dependent on national funding sources (that may emphasize different priorities) (Ponds, 2009).

The initial concept of the triple helix model has been extended to another “helix,” including the public (Carayannis and Campbell, 2009), and then the nature as a significant knowledge source (Carayannis and Campbell, 2010). Even this model has been developed into the N-tuple helices model (Leydesdorff, 2012; Park, 2014), which considers the role of various actors in shaping innovation processes in the context of different national innovation systems and countries at different development levels.

Those new spheres include, for instance, non-commercial entities such as hospitals (Godin and Gingras, 2000; Lander, 2013; Yoon Yang, and Park, 2017) and non-governmental organizations (NGOs) (Lander, 2013; Olivier, Hunt and Ridde, 2016; Yoon Yang, and Park, 2017). Taking into account those additional types of research collaboration partners is justified because of benefits such as opportunities for mutual learning and complementarities in expertise (e.g., training of research students, collaboration on the design of a research project), improved knowledge translation, increased access to communities and government representatives and adapting research to reflect better local realities (NGOs have better opportunities to collect data) (Olivier, Hunt, and Ridde, 2016).

We should also be aware of the specific challenges that may hinder collaboration between those sectors, namely: asymmetric power relations (as researchers are usually responsible for the supervision of the research design and planning, as well as they have direct access to funding); divergent goals and approaches (academics focus on scientific publications while NGOs representatives on achieving behavioral or policy change in a specific community), lack of recognition for the contributions made by each partner (as science conducts following standards of methodological and scientific rigor, while NGOs reveal a more pragmatic approach to research and their assessment of its utility), and impediments to respect within partnerships (Olivier, Hunt and Ridde, 2016).

The growing importance of those other entities in research processes prompted me to extend traditional triple helix spheres and explore interactions between science, commercial as well as non-commercial sector (S-C-N), which was adopted after Lander (2013) (Lander (2013) in her study, despite the initial distinction between commercial and non-commercial institutions, explores the role of five sectors, namely universities, firms, governments, NGOs and hospitals, as those types of entities act as important actors of biomedical research processes.

This paper presents an investigation for all the domains within which scientific projects were launched in 2019 in Poland and recorded in the POL-on database. That is why all the non-commercial entities were coded as the one set.). The criterion for the distinction was the core mission of each institution type (Table 1).

**Table 1.** Sectors distinction within cross-sectoral research collaboration analysis used in the study

Sector	Types of entities	Core mission
Science	Universities and public research organizations	Knowledge creation, development and dissemination
Commercial entities	Private and state companies (incl. private commercial laboratories and spin-offs)	Utilization of knowledge for organization's individual economic benefits (profit generation)
Non-commercial entities	Governmental and self-governmental bodies, state offices, state agencies for research financing, NGOs (such as foundations, citizen associations), hospitals (incl. university hospitals)	Utilization of knowledge for the public benefits

*Source:* Own elaboration.

## 2.2 Different Relations Within Knowledge Production Network

Exploiting the benefits of cross-sectoral knowledge interactions requires the linkages between different hierarchical perspectives (intra-regional and supra-regional) as embedded economic development depends on combining internal and external knowledge sources (Ascani, Bettarelli, Resmini, and Balland, 2020; Miguelez and Moreno, 2018). Scientific institutions seem to be effective intermediaries in this field (Graf, 2011), not only through their participants in global scientific networks but also by creating linkages with other sectors. Ponds, Oort, and Frenken, (2010) argue, for instance, that university-industry linkages connect regional economies to supra-regional networks, as the academic research conducted in the global community of scientists could be applied to the industry sector and developed further within regional knowledge clusters.

The significant role of the science within cross-sectoral research collaboration has been confirmed in empirical studies from different countries and within various domains (Godin and Gingras, 2000; Khan and Park, 2013; Kwon, Park, So, and Leydesdorff, 2012; Lander, 2013; Leydesdorff and Sun, 2009).

However, despite the advantages of establishing research partnership within global networks, internationalization of collaboration should not be the only objective in this matter as joint research conducted with regional and local partners (that share our norms, values, language) helps us to benefit from close physical proximity on lower expenses of search, coordination and communication activities (Hoekman, Frenken, and Tijssen, 2010). Moreover, the priority for choosing foreign partners may provide to the erosion of domestic and regional knowledge production systems. Kwon, Park, So, and Leydesdorff (2012) noticed that the Korean incentives in the 1990s for international research collaboration brought the synergy effect for intersectoral knowledge exchange.

However, since the 2000s, the development of the Korean R&D publication system seems to stagnate (university and industry sectors publish widely with foreign authors, but at the same time, those sectors exchange the knowledge with each other less frequently). This conclusion was quite similar to Leydesdorff and Sun's (2009) study conducted for Japan (decline of domestic university-industry linkages) and Canada (decline of domestic university-government relations).

In this place, there emerge the necessity of establishing a careful balance that should be achieved between regional and supra-regional linkages. According to Cai and Etkowitz (2020), in this context, there could be adopted social network theory, as two fundamental concepts are the base for further considerations, namely weak ties (Granovetter, 1973) and structural holes (Burt, 1992). Granovetter (1973) recognized two types of relations that connect network actors differently. Strong ties exist between entities that share a set of contacts (so there is a high likelihood that they both are related to the same node), in contrast to weak ties that do not reveal the apparent tendency for overlapping relations. Strong ties build closed networks and provide conditions for better knowledge integration within innovation processes (Michelfelder and Kratzer, 2013; Tiwana, 2008) and raise the trust between entities (Guan and Zhao, 2013).

On the other hand, they also result in increasing homogeneity and knowledge redundancy, which have a negative impact on the creativity and competitive advantage of individual members of such a cohesive group (Burt, 1992). That is why bridging ties (understood as weak ties that link nodes from separate clusters) within the network structure is desired. Bridging ties span the structural holes that may occur in bridging tie breakage (it would disconnect the network and divide it into separate components). Those types of linkages provide access to diverse, external resources and innovation potential and create opportunities for further knowledge diffusion (Gretzinger, Hinz, and Matiaske, 2011; Tiwana, 2008). Scholars argue that stimulating knowledge processes within networks requires combining both types of the mentioned ties (Cai and Etkowitz, 2020; Michelfelder and Kratzer, 2013; Tiwana, 2008).

Michelfelder and Kratzer (2013) even suggested that public financial support for rising the innovation potential should be directed to fewer but larger networks or should enhance establishing links between several smaller networks and connecting them into a larger one, that would be characterized with the combination of the firm as well as bridging ties. Thus, it seems necessary to explore the actual network structure of research collaboration in Poland, with thorough recognition of crucial ties and key intermediary nodes. Such analysis may help to evaluate the public financing system of Polish science.

Moreover, the science sector institutions may apply the research results to their strategies to succeed in research and development activities; they need to increase their relationships with actors that are most influential within the scrutinized network (Santini *et al.*, 2021).

### 2.3 Polish Approach to Cross-sectoral Research Collaboration

Innovation is a driving force for economic transformation in Central and Eastern European countries (Jankowska, Matysek-Jędrych, and Mroczek-Dąbrowska, 2017), and that is why the knowledge processes are crucial for their future. Despite efforts that were undertaken to raise the level of its innovativeness, Poland is still the moderate innovator with Linkages as the weakest innovation dimension (European Innovation Scoreboard 2020; 2020), to which the low level of public R&D expenditures that were co-funded from private sources contributed most. The share of private-sector R&D performers grows but is still low in comparison to other EU countries. Policymakers in Poland tried to enforce science-industry linkages by offering funding for scientific institutions only in collaboration with industrial partners (Klincewicz and Marczevska, 2017). As a result of those policies, the Polish business sector conducts cross-sectoral innovation cooperation, mostly with higher education institutions and public research organizations (GUS, 2020). What is quite specific, although in Polish economy dominates privately-owned companies (large number of SMEs), the focus of policymakers is put on those state-owned (Klincewicz and Marczevska, 2017). They consume many public research grants also those for research collaboration.

Thus, as the growth of R&D collaboration is primarily induced by public co-funding, this elaboration considers only those scientific projects that were financed (or co-financed) from public sources.

### 3. Research Methodology

One of the most popular quantitative methods for research collaboration study is the bibliometric analysis (Kwon, Park, So, and Leydesdorff, 2012; Lander, 2013; Ponds, 2009; Yoon Yang, and Park, 2017) as well as the use of patent co-inventorship (Ortega, 2011; Pinto, Vallone and Honores, 2019) or co-ownership data (Messeni Petruzzelli and Murgia, 2020). These approaches reveal some limitations as they focus on visible outputs of research collaboration, which are not the only possible results of such activity (there may also emerge new concepts or secret know-how).

Moreover, Katz and Martin (1997) mention that multiple affiliations of an author may artificially generate data about cooperation between institutions. Ahn, Oh, and Lee (2014) find that bibliometric studies focus on the benefits of cooperative research rather than examining partnership tendency at the foundation stage of scientific collaboration. We also should be aware that not all the collaborators need to participate at all stages and are not necessarily interested in publishing the research results. That is why some authors assume that different measurement methods are relevant for different stages of research collaboration (Wanzenböck, Scherngell, and Brenner, 2014; Yuan *et al.*, 2018) and include information about co-participation in scientific projects as another indicator for inter-institutional interactions in this field.

D'Este and Patel (2007) mention that contract research agreements are more frequent in public-private interactions than patenting or licensing. This type of data, despite it seems to be reasonable for the investigation of formal linkages which results instead from organizational than individual decisions, has been rarely used in studies on research collaboration that may be observed between institutions (Scherngell and Barber, 2011; Yuan *et al.*, 2018). Research presented in this paper is another example of elaboration carried out from such a data perspective.

In order to illustrate the network structure of publicly financed research partnership between Polish scientific institutions and non-science entities, there is collected data from the POL-on “scientific projects” database - an integrated system of information on science and higher education in Poland POL-on is a tool that supports governmental decisions related to the science/research sector and a system for obligatory report submissions of scientific units located in Poland. The recorded data relates to the research financed from various public funds within various programs (incl. the local ones).

There were identified 3313 scientific projects launched in 2019; 205 were conducted in participation at least two entities (with at least one scientific partner from Poland). From this dataset, there were selected 97 scientific projects realized by at least one scientific unit from Poland and at least one non-scientific entity. There were excluded projects financed entirely by the business sector (Commercial projects should not be considered as not all of them would be necessarily included in the dataset because companies that collaborate with scientific institutions may reserve confidentiality in this field.). This research sample was based on undirected 2-mode network construction (with two types of nodes: projects and participants assigned to them). In the subsequent step, the network was transformed into the 1-mode network, which presents the linkages between institutions (assuming that connections are reciprocal and each project participant is connected to every other participant in the same project).

Batagelj and Mrvar, (2004) was applied for network visualisation and calculation of chosen measures, namely (Nooy, Mrvar, and Batagelj, 2011):

- components -a set of graph vertices (subgraph), within which there exist direct or indirect connections between all pairs of vertices,
- bi-components -section of a network which is invulnerable to the deletion of a single vertex (as it is internally well connected), that may be connected with other bi-component by cut-vertices whose deletion increases the number of components in the network (they are linking nodes that create bridging ties),
- degree centrality -the degree of a vertex means the number of connections of a given vertex with other,
- closeness centrality -shows that a node has shorter direct and indirect ties with other actors, which means better access to the greater network area and less



- dependence on others (is calculated as the reciprocal of the sum of the length of the shortest paths between the node and all other nodes in the graph),
- betweenness centrality -identifies critical vertices which potentially have the most control overflows in the network (is calculated as the ratio of the shortest paths between pairs of other nodes that contain this vertex).

#### 4. Results

***Bimodal network of scientific projects:*** Among 3313 scientific projects noted in the POL-on system, launched in 2019 with the participation of at least one scientific institution located in Poland, only 205 were carried out in partnership (it is less than 1%). Nearly half of them (97) included at least one non-scientific partner (commercial or non-commercial), and none was financed fully from private sources. Within the bimodal network of those selected projects, there were identified 25 international projects (with at least one entity located outside of Poland), 47 domestic projects (that gather partners from different regions of Poland), and 25 intra-regional projects (all partners are located in the same province). Over half of initiatives that are embedded locally took place in the Masovian region. There was also recorded a total number of 438 organizations (Table 2).

Quite a large share of domestic, commercial entities may be observed within the network. Six multiple lines were observed what means that in some cases, two or more organizational units (e.g., different faculties from the same university) co-participated in the same project).

**Table 2.** *Participants of scientific projects conducted in science and non-science partnership in 2019 by sector and location (Polish science perspective)*

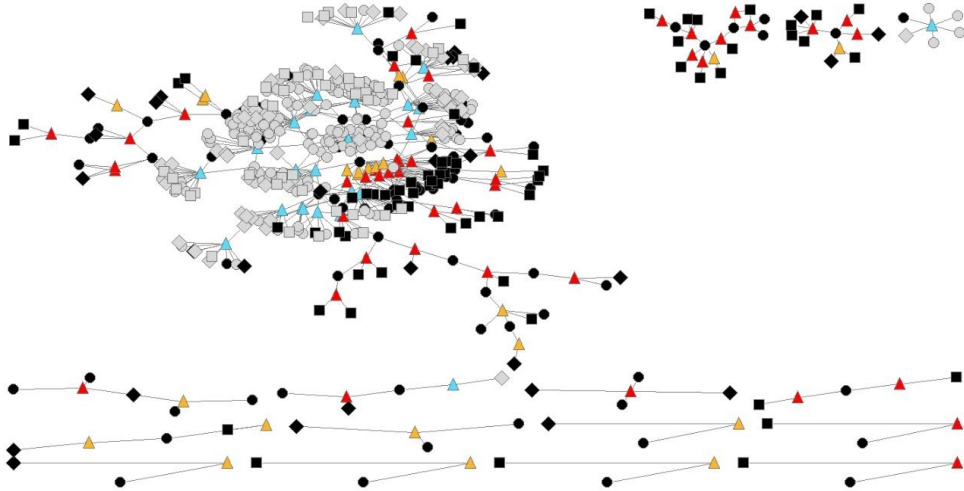
Sector	Location		Total
	Poland	other	
Science	81	163	244
Commercial	71	41	112
Non-commercial	29	53	82
Total	181	257	438

**Source:** *Own elaboration.*

The identified network consists of 16 components, and the largest one covers over 82% of the area. It means that there exist entities that, by participants in different initiatives, establish connections between different parts of this structure. Most international projects and foreign entities may be noticed within this significant component due to the large multinational consortia that implement research ventures often sponsored by EU funds. Scientific institutions usually link those large projects, but only 6 Polish science sector representatives within this structure and a single domestic company participated in more than one international research project in 2019. However, there are also observed scientific institutions that provide international cooperation and participate in domestic and intra-regional initiatives at

the same time (12 organizations), which includes domestic as well as intra-regional projects into the most significant component. Small, separated components (single projects that include 2 or 3 partners that did not participate in any other cross-sectoral research initiative in 2019) are usually local (Figure 1).

**Figure 1.** 2-mode network of scientific projects conducted in science and non-science partnership in 2019 (Polish science perspective)



**Note:** Triangle - a project: blue - international, red - domestic, yellow - intra-regional; circle - science sector; box - commercial sector; diamond - non-commercial sector: black - domestic, grey - foreign.

**Source:** Own elaboration based on POL-on.

Calculation of the degree centrality (after removing multiple lines) enabled to indicate projects with the most significant number of partners (with the first rank position of the initiative conducted in partnership of 44 entities from different countries) and the entities that participated a most significant number of projects. Warsaw University of Technology achieved the first rank position in this field as it participated in 17 different cross-sectoral research ventures in 2019. The following positions were achieved by the Central Mining Institute (9 projects) and the University of Gdansk (8 projects). Three hundred sixty entities identified within the network created a single linkage (participants in a single project) - over 55% of the domestic science sector and over 80% of Polish commercial and non-commercial entities. There were only three domestic companies, three governmental bodies, and one non-profit organization that took part in two research initiatives in 2019.

Over half of international projects involving partners from all the three sectors, while domestic and regional collaboration is usually conducted between science and the other sectors separately. At the domestic level, there is visible the priority of commercial organizations (Table 3).

**Table 3. Collaboration between sectors by project range**

Range of project	Research projects conducted in collaboration between sectors					
	S-C		S-N		S-C-N	
	Value	Percentage	Value	Percentage	Value	Percentage
international	4	16%	7	28%	14	56%
domestic	32	68%	13	28%	2	4%
intra-regional	14	56%	10	40%	1	4%

**Note:** S - science sector, C -commercial sector, N - non-commercial sector.

**Source:** Own elaboration.

**Table 4. Centrality measures (first ranking positions) by sector**

Sector	Organization	Centrality measure							
		Degree		Closeness			Betweenness		
		Value	Rank	Organization	Value	Rank	Organization	Value	Rank
<b>Science:</b>									
domestic	Warsaw University of Technology	90	1	Warsaw University of Technology	0.4180	1	Warsaw University of Technology	0.2016	1
foreign	Universidade de Aveiro Consiglio Nazionale delle Ricerche	77	2/3	The University of Edinburgh	0.3927	2	The University of Edinburgh	0.0719	4
<b>Commercial:</b>									
domestic	Tauron Wydobycie S.A.	13	178/202	Eurotech Sp. z o.o.	0.3030	130	Sonovero Sp. z.o.o.	0.0020	56
foreign	MINTEK Warrant Group Srl Green Decision UppinTech OÜ European Research Services TEMAS AG Technology and Management Services Ideaconsult Limited Liability East European Research and Innovation Enterprise Ltd	35	58/86	CSC-TIETEEN TIETOTEKNIKAN KESKUS OY	0.3166	63/86	SUBTERRA INGENIERIA SL	0.0025	55
<b>Non-commercial:</b>									
domestic	Central Office of Measures	14	177	Central Office of Measures	0.2941	143	Central Office of Measures	0.0007	59
foreign	Agencia Estatal Consejo Superior de Investigaciones Cientificas	65	10/12	Agencia Estatal Consejo Superior de Investigaciones Cientificas	0.3531	16/18	Fraunhofer Gesellschaft	0.0414	10

**Note:** \* degree centrality was calculated after loops reduction.

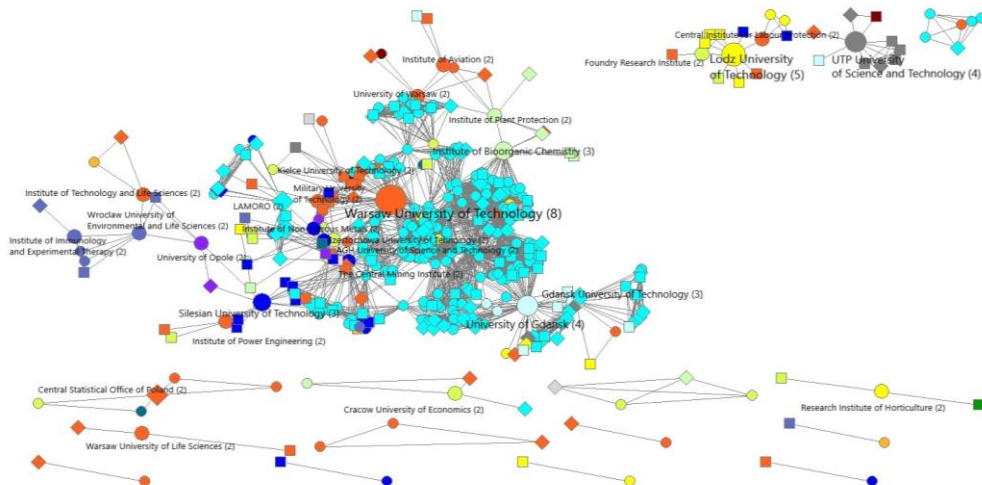
**Source:** Own elaboration based on POL-on, calculated in Pajek64 5.11.

A 2-mode network was transformed into a 1-mode network of organizations connected by participation in the same project. In this network, a total of 3757 connections of 438 entities were recorded, of which 86 are multiple relations (when two organizations participate together in the implementation of several different projects). The multiple lines noted in the 2-mode network have been transformed into six loops observed within the 1-mode network. At this stage, degree centrality, closeness centrality, and betweenness centrality were calculated for each of the vertices (Table 4).

Warsaw University of Technology achieved the first ranking position in all those measures and is a dominant network entity. In 2019 this higher education institution researched science -non-science projects with 90 entities. Central Office of Measures also ranks first among domestic non-commercial entities, but in comparison to foreign organizations, it takes a distant position. Within the identified network foreign non-commercial sector reveals greater access to other nodes and more significant potential influence on the knowledge flows between participants than the commercial sector as no dominant company (domestic nor foreign) is notices.

At the next stage, there were recognized 60 bi-components and 28 cut-vertices. Most of them are domestic universities and public research organizations (Figure 2). However, two non-commercial organizations also reveal belonging to two bi-components, namely: the Central Statistical Office of Poland, as well as Societa Consortile, are Langhe Monferrato Roero (presented by LAMORO label in Figure 2), which is an Italian territory development agency.

**Figure 2.** Cut-vertices within 1-mode network with region distinction



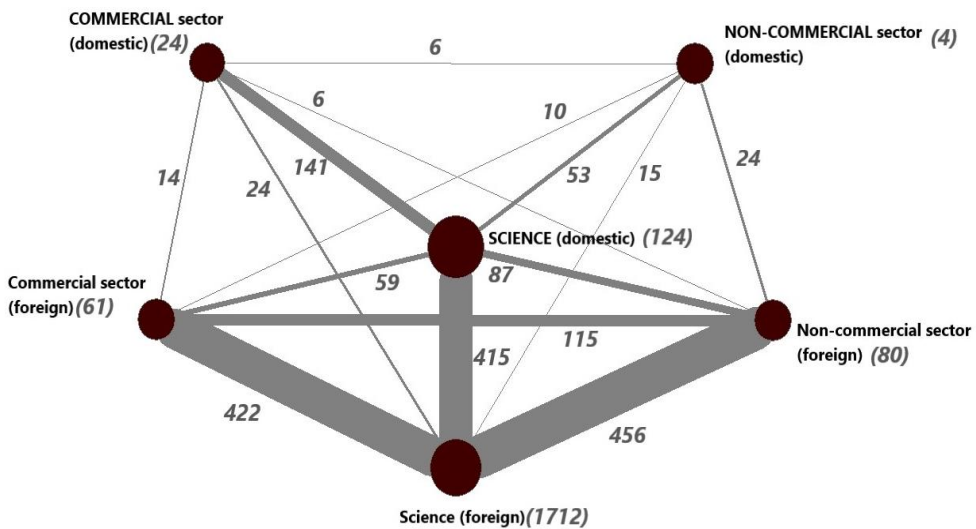
**Note:** Colors of vertices represent location in region (blue represents foreign actors). Number in brackets means the number of bi-components a vertex belongs to, which is also illustrated by vertex size.

**Source:** Own elaboration based on POL-on.

Among recognized cut-vertices, we may distinguish 4 Polish scientific institutions (namely Warsaw, the University of Technology, the University of Gdansk, Gdansk University of Technology, and the Institute of Bioorganic Chemistry) (international, national, and local) establish bridges between them. Another four entities (The Central Mining Institute, University of Warsaw, Silesian University of Technology, and the Cracow University of Economics) link foreign and domestic inter-regional levels. The rest of identified cut-vertices does not create relations with entities from other countries. Most public research organizations, as well as universities, cooperate with companies that are located in the same region. This tendency is not so evident in the case of the non-commercial sector (as many governmental bodies are located in the central Masovian region).

At the final stage, the 1-mode network has been shrunk to show a total number of relations between specified sectors (Figure 3). Loops (intra-sectoral relations) are presented in brackets.

**Figure 3.** Shrunk network of relations between sectors



**Source:** Own elaboration based on POL-on.

International research collaboration is conducted within large inter-sectoral and multi-partner initiatives what establish a dense network of potential knowledge exchange. There is observed a kind of balance between S-C and S-N relations of foreign entities. However, despite the broad collaboration with both sectors, intra-sectoral connections still dominate (as most partners in these international projects are scientific units). Polish scientific institutions are linked to this worldwide research environment, primarily by numerous co-participants in projects with foreign scientific actors. They have an opportunity to make connections with the foreign non-commercial sector and slightly less often with foreign companies. There is a gap between domestic

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commercial and non-commercial sectors (only six relations), as Polish science cooperates with them separately (more willingly with business). The poor collaboration inside the domestic non-commercial sector is also noticed.

## **5. Conclusion**

In 2019 inter-organizational research partnership is still an exception for Polish science. However, in the POL-on database, there were reported some cases of publicly funded inter-sectoral research partnerships. Polish scientific institutions conduct those projects at different hierarchical levels, and nearly half of them involve partners from different domestic regions. The balance between projects of the local and international range is also visible.

International research collaboration usually means the participation of a single or few Polish organizations in large consortia. A numerical predominance of the foreign scientific sector is visible, but more than half of international projects reveal trilateral partnerships between S-C-N sectors. It creates for domestic entities ample opportunities to access various foreign organizations and results in strongly connected parts of the identified network. On the other hand, maintaining solid relationships with numerous partners requires higher time and cost consumption (Hoekman, Frenken, and Tijssen, 2010).

Domestic and local research collaboration is realized in relatively more minor projects usually conducted bilaterally between science and other sectors. Although joint research with business dominates among those initiatives, which confirms insights (Klincewicz and Marczevska, 2017), the commercial sector does not reveal an influential position within the network structure. Companies are usually peripheral nodes and appear to be consumers rather than intermediaries for those potential knowledge flows. Also, domestic non-commercial sector representatives do not take a significant position in this structure. In the light of the triple helix concept, more intensive trilateral coordination may seem desirable (Etzkowitz, 2008), but mutual adjustments between two types of partners are also enough to reduce the uncertainty of the third type (Leydesdorff and Sun, 2009). That is why self-organizing of those adjustment processes should be allowed, while the science should be aware of its role within those processes.

Warsaw University of Technology is a dominant entity recognized within the identified network. It achieved the highest results in all the centrality measures, suggesting its broad access and strong potential influence on other actors. By its engagement in 2 international, nine domestic, and six intra-regional projects, the university establishes linkages across different hierarchical levels and between separate parts of the network. This strategic position could be utilized to integrate knowledge from different sources and within various domains (by developing conditions for multidisciplinary knowledge exchange). The analysis was conducted for all the domains that may result in undermining the intermediary role of a scientific

institution. If it participates in projects of a specific domain, the knowledge would not necessarily be passed on to participants of another project of another domain.

The presented study reveals some limitations that should be considered in future works. The collected data determines the egocentric nature of the presented network, which limits the possibility of inference only in the context of Poland and from the science sector perspective (as the bilateral relations between commercial and non-commercial sector has not been recorded as well as their direct linkages with foreign entities without the participants of domestic research institutions). There also should be noticed that the POL-on database does not necessarily include projects covered by the protection of classified information regarding defense and the security of the state. Moreover, the relatively short period was analyzed what results in the static approach presented in the research. Conducting similar research in dynamic terms (considering the change in the network structure over time) may provide further conclusions.

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