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DOMINIKA CZERNIAWSKA
University of Warsaw

WOJCIECH FENRICH
University of Warsaw

MICHAŁ BOJANOWSKI
Kozminski University

Actors, Relations, and Networks: Scholarly Collaboration Beyond Bibliometric Measures

Abstract: Scholarly collaboration is relatively well described quantitatively on the macro level thanks to the analyses of large bibliographic databases. At the same time, there are known limitations of the bibliometric approaches to studying collaboration in science. We argue that in order to improve our understanding of social processes operating in science it is necessary to take a more in-depth look: (1) identify kinds of actors that are recognized as potential partners in collaboration, (2) what features of collaborative relations are considered crucial for engaged actors, (3) what kinds of structures of networks composed of collaboration relations actors are embedded in, and what factors influence these structures. With 30 individual in-depth interviews (IDI) with Polish scholars we gathered detailed information about individual collaborations that allowed us to analyze collaborative ties from individual perspective and map respondent-centered networks of collaboration. Scholars identify individuals as well as teams or institutions as collaborators. They also distinguish symmetric and asymmetric collaborations. Structures of respondent-centered collaboration networks are affected by (a) leadership strategies of team principals (especially whether teams are built around positions or individuals); (b) institutional location (by making establishing external collaborations easier for scientists from bigger institutions); (c) scientific degree and recent changes in financing of science (as young scientists receive more freedom from usual organizational hierarchies by receiving substantial grants).

Keywords: scholarly collaboration, social networks, gender, core-periphery, ego-networks

Introduction

Among many changes, Academia experienced in recent decades the growth of scientific collaboration is perhaps one of the most visible. It is followed by the intensification of research on scholarly collaboration. Despite the effort, current understanding of collaboration is still fragmented (Katz and Martin 1997; Beaver 2001). It is mostly because of a multiplicity of distinct approaches, e.g., naive empiricism based on co-authorship data or discipline-specific approaches, for example in innovation studies (Sonnenwald 2007). These approaches share two characteristics, which can be questioned. Firstly, the co-authorship approach, which has dominated many collaboration studies since the work of de Solla Price (1965), assumes that co-authorship data provides an unbiased representation of collaboration. An exemplary source of bias is that scholars might have different notions of

authorship and the scope of work required to become a co-author. Moreover, co-authorship data does not provide information on informal help nor on collaborations that fail. In other words, we argue that to dissect social mechanisms (Hedström 2005) of collaboration in science we should look beyond the co-authorship networks and unravel the story behind the co-authorship graph. These stories exist in the minds of individual scholars.

Secondly, collaboration has been operationalized as a tie between individual scholars. However, collaborators may be actors of different kinds. For example, actors engaging in a relation may be individual scholars, i.e. "natural actors," teams, or institutions as a whole, i.e. "corporate actors" (Coleman 1990). Differences between these entities are probably most apparent when one would examine how collaborations are negotiated and later implemented. We can think of situations, in which collaboration may be established by leaders of two scientific teams whereas the actual collaborative work is performed by individual members of these teams. Nevertheless, in such collaborations scholars may anyway perceive as a collaborator the other group as a whole without being able to single out particular individuals. In other words, the group is recognized as a collaboration partner, not particular individuals. There may be also other dimensions, apart from the analytical level, on which actors recognized by scholars as collaborators differ. Therefore we would like to propose a new category of 'elementary actors' in collaboration based on work of (Coleman 1990).

In principle collaboration is a voluntary relation. Scholars enter collaborations with others because they perceive it as more beneficial as compared to doing research alone. The weighing of "benefits" by an individual scholar takes place in a complex social environment in which various factors have to be taken into account. One example is skills and competencies. We can imagine an individual scientist having a research problem at hand and considering whether he/she has all the required skills to tackle this problem. If the answer is no, should he/she try to learn the missing skills or perhaps look for a collaborator who will bring complementary skills to the research project. Another example is a relation of exchange of intangible resources e.g. visibility or status. Some research fields are dominated by small number of prominent scholars. Collaboration with them, perhaps on top of other benefits, may be desirable because the joint work will attract much higher attention as compared to a situation in which the same project is executed by a different person with similar skills, but the lower status or visibility. Obviously, one can come up with other examples too: how authority/power affects collaboration, and so on. Given that collaboration in science can take various forms (Katz and Martin 1997), it makes collaborative relations as such necessarily *multiplex* (Kapferer 1969; Kuwabara et al. 2010). These network structures can be very different. On the one hand, they can be rather "hierarchical" such that if a scholar has many collaborators, these collaborators are unlikely to collaborate with one another. On the other hand, personal networks can be denser and "egalitarian" such that everyone is likely to collaborate with all others in a more cohesive group. Therefore, we would like to ask:

1. What structural characteristics do the individually perceived collaboration networks have?

Moreover, hierarchies may overlap and change significantly over time, e.g. former student might one day become a dean or engage former professor in a research grant. Formal

hierarchies do not always reflect the real structure and relations between collaborators. Actual relations, which can be for example a product of funding agency's requirements, add new or reverse existing authority relations. We can find different incentives to collaborate, which rely on diverse organizational and institutional factors. For example, it has been argued that scientific fields are characterized by various interdependencies and uncertainties which result in different organizational structures (Whitley 2000). There may be also other individual-level and institution-level factors that affect how collaboration relations are formed and how this process is perceived, which begs the question:

2. How do the structures of personal collaboration networks differ depending on institution-level factors (core vs periphery institutions), or individual-level factors (seniority)?

To answer these research questions and understand the process that leads individual scientists to enter collaborations with others it is necessary to take an individual or *ego-centered* research perspective. We need to give the subjects the freedom to describe their social environment, express their motivations to collaborate, define collaborators, and provide more detail on collaborations that they are engaged in. An appropriate research technique in that context is an individual in-depth interview (IDI). Based on 30 of such interviews we provide insights with respect to the above questions.

The impact of various social mechanisms on collaboration networks is usually investigated to the extent limited by information available in bibliographic data. Enriching such data with more detailed information about collaborations and researchers involved has been rarely done. Our paper aims to investigate collaboration structures in a detailed way by introducing a novel methodological approach of distilling information on collaboration networks from semi-structured interviews. The approach enables us to reveal different types of collaborators (e.g. group actors) and explain diversity in structure of collaboration networks. It also exposes the existence of collaborations crucial for scientific work that are invisible in publication records. The remainder of this article is structured as follows. In the next section we elaborate on the research questions and review the literature tackling similar problems. It is divided into 3 sub-sections: Actors, Relations, and Networks. In section "Data and methods" we describe in more detail the design of the qualitative study: the data collection process, the sample, and the interview script. In section "Results" we describe our findings. The article is concluded with the "Discussion" section.

Scholars, Scholarly Research, and Collaboration Networks

The research questions posed in the previous sections correspond to three different levels of analysis: actors, relations, and networks consisting of relations built by actors. These three analytical levels complement into a more comprehensive picture of collaboration in science. Below we elaborate on each of these levels with respect to our research questions.

Actors

Scholarly collaboration have been studied empirically using data on co-publication, co-patenting, engagements in grants, or institutional affiliations (Katz and Martin 1997). It is

probably fair to state that studies on scholarly collaboration in general, have been dominated by the empirical studies, and of this type (see for example Subramanyam 1983 for a review). However, the nature of the data determines the type of actors which might become a collaborator, namely, an individual scholar.

Coleman (1990) introduced the concept of *elementary actors* who are action-taking social entities that have interest in and, possibly, control of certain resources. Elementary actors can be *natural persons* or *corporate actors*, e.g. groups, organizations, or institutions. A group of individuals might become an elementary actor if it is recognized by others as having interest in or control of resources, and a capability of expressing these interests and exercise the control. For example, religious groups in Lebanon in 1945 gained such recognition from other political actors, which was then acknowledged in the constitution (Coleman 1990, ch. 13). We might expect that these concepts also apply to scholarly research as resources and their control are associated not only with individual scholars (natural persons), but also with scholarly teams and institutions (corporate actors). What makes this distinction crucial is the fact that some forms of scholarly collaboration involve processes of exchange of resources. We might therefore theorize that scientists might perceive as collaborators relevant elementary actors, which involves *both* individual scholars as well as groups, organizations, or institutions.

Relations

There are many types of collaborative activities, such as integration, application, referring, or teaching (Boyer 1997). There have been also several attempts to classify collaborations within roles undertaken by scholars. The typologies seem to primarily focus on structural dependencies and distinguish master-apprentice relations, peer collaboration, supervisor-assistant collaboration, researcher-consultant collaboration, collaboration between organizations, international collaboration and so on (Subramanyam 1983). Lewis et al. (2012) introduced a distinction between "collaboration" and "Collaboration" (with capital "C"), where the first term describes situations in which the relation is fluid, mostly relying on discussion, feedback, and commentary while the second is more tangible, concrete, and instrumental, including designing and conducting a study together as well as later publications. The definition appears to be flexible enough to capture the richness of academic collaboration.

Collaboration is voluntary relation but it is established in complex social settings, primarily different organizational structures, which determine the scope of possible relations. Research institutions and higher education institutions evolve over time and undertake different organizational frameworks (Middlehurst and Elton 1992), encouraging employees to perform in various roles as scholars, teachers, or managers (Slaughter and Leslie 1997). It has a direct impact on collaboration networks of scholars. Organizational changes of institutions are very much connected to new expectations toward universities and research institutes, like popularization of higher education or collaboration with industry (Blau 1994). As previous research shows, countries vary a lot when it comes to the coherency of organizational frameworks and institutional coordination (Whitley 2003). There are several leadership models identified in academia. First one is "organized anarchy," which combines

individual freedom and responsibility coming with professionalism. It requires efficient vertical and horizontal information flow (Cohen and March 1974). The second model is the "cybernetic model." Despite the absence of tight structures of management in traditional universities, they were stable and efficient institutions (Birnbaum and Edelson 1989). It is most likely possible due to a self-correcting mechanism, which has not been understood yet. Recent research indicates the emergence of a new type of scholar, primarily active in teaching and research but also focusing on the management, establishing research-based services and facilitating the core functions of research and teaching: the so called New Higher Education Professionals model (Schneijderberg and Merkator 2013). Scholars might decide to develop looser or tighter collaborations within their research groups depending on such leadership models. For example, "organized anarchy" would require closer collaboration because of the way the information flow is organized. In contrast, the New Higher Education Professionals model is closer to business management and therefore might result in more fragmented teams focusing on well-defined goals. There have been no research how different leadership strategies affect establishing collaboration ties within leader's group and how it affects the structure an *ego-networks*, on which we would like to focus in later sections below.

Networks

Exogenous factors might also have an impact on whole collaboration ego-networks that include collaborators in the sense of broader definition of collaboration introduced above. In our exploratory study, we are also interested in investigating, following our research question 3, if the collaboration networks mentioned above are differentiated by any exogenous factors. We elaborate on the role of one factor: core/periphery structure of science.

The core-periphery phenomenon is widely observed in many social processes, e.g. in economic, technical, or scientific development (Baldwin and Forslid 2000). It can be identified at different analytical levels: individual, institutional, country, or global level. Previous research shows that more peripheral actors have limited access to resources and potential collaboration partners (Lepori et al. 2013). In contrast, core actors collaborate more often with one another and less often with actors from the periphery. The core-periphery divisions also tend to deepen over time (Leydesdorff and Wagner 2008). According to the literature, we should be able to trace similar type of variations in individual collaboration networks. Scholars from core institutions might be expected to have more developed collaboration networks, but mainly with other scholars from core institutions.

Since scholars from peripheral and core institutions are more interested in collaboration rather with the core institutions, we can expect little collaboration between scholars from peripheral institutions. An example of closer collaboration between core institution can be found in PhD hiring among top universities, when top-tier sociological departments hire almost exclusively graduates from other top-tier departments regardless of personal achievements like publication scores (Han 2003).

Furthermore, peripheral institutional location might affect professional goals of scholars. Hermanowicz (1998) shows that the spectrum of activities included in the process of constructing a professional self depends on the rank of affiliated institutions. Scholars from

top-rank universities focus almost exclusively on research achievements, whereas scholars from less-established institutions include their engagement in teaching or local communities. Pursuing different goals require different collaboration strategies, which results in different collaboration structures.

Individual characteristics of scholars might also affect differently collaboration networks in different organizational settings. A result of professionalization in academia is a more rigid path of professional development (Crosland 1975; Beaver 2001). However, Kwiek (2015) shows that all East-Central Europe countries struggle with transformation of higher education system. Polish scholarly system is still a mix of norms remaining from previous period and the new one based on the recommendations from the World Bank, OECD, Europen Union, and other global institutions. Therefore, we can expect diverse organizational structures, responding to different norms. The first one would be more conservative and built around governmental subsidies to universities. The second one would be more modern, closer to Western models and built around grant-based funding dedicated to research.

Traditional milestone of a career advancement in academia is earning an academic degree: PhD, habilitation and professorship. Formally, a scholar has to be habilitated to be independent. Becoming one grants the access to valuable resources namely department and unit boards and control over money. Consequently, a scholar with habilitation can manage people and collaborations, run teams and labs. Despite the mix of organizational structures mentioned above, we expect that traditional hierarchy marked with academic degree plays the most important role. Therefore, scholars with habilitation would be the most attractive to collaborate with and have the most developed collaboration networks.

Data and Methods

The study is based on thirty individual in-depth interviews conducted between September 2014 and January 2015 in four Polish cities. Eighteen interviews were conducted in two major academic centers (we call them "central") and twelve took place in two less significant academic cities (which we call "peripheries"), but still being recognized by some outstanding performance in particular disciplines. Appendix provides a table with basic information about the respondents. In the sample we have 16 men and 14 women, 18 scientists from central and 12 from peripheral institutions.

Information about scholarly achievements was used during the recruitment process. To understand scientific collaboration through actual collaborative behaviors, only scholars with at least some track of collaboration experience (e.g. co-authorship, membership in research groups, and so on) were invited to the interview. However, scholars differed greatly in the extent of collaborative work and in the number of brief or long-term collaborations. Restricting the sample to scholars with at least some collaborative experience allowed to use the same interview script and avoid speculative opinions, which are not related to real situations of particular interviewees.

Scholars were invited via an email. One-to-one interviews were conducted at time and place convenient for the respondents. The interview was semi-structured. In other words,

the interviewers used a script, but it was not strictly followed as in a questionnaire-based interviews. The script consisted of several groups of topics including:

- details of ongoing collaborative relations
- characteristics of current collaborators
- general opinions regarding collaboration and competition in science
- academic and non-academic collaboration.

A typical interview took between 40 and 90 minutes. Each interview was conducted by one person. Interviews were recorded, transcribed, and annotated with MaxQDA software with two coding schemas. The first coding schema was designed in order to obtain lists of collaborators with characteristics including:

- gender and country of residence
- shared research team and institutional affiliations
- details of the collaborative relation including intensity, time of collaboration, formal agreements
- control of research funds
- authority relations and project/team leadership.

The second coding schema covered a more broad information about aspects of collaboration and collaborators including information about the meeting places, the reasons for collaboration, arrangements of collaboration, and more broadly convictions about scholarly collaboration and characteristic of ideal collaborators and collaboration team. For example, in the following fragment the respondent describes her two collaborations:

[The research] was my colleague's idea. He proposed that I join him. He is the leader of a funded project, and I am a researcher in that project. We have also invited one other colleague from a university because it is an experimental study and I knew that he was good at it. I met this colleague from a university at a conference and we talked there. I did not collaborate with him before. [Social Scientists I]

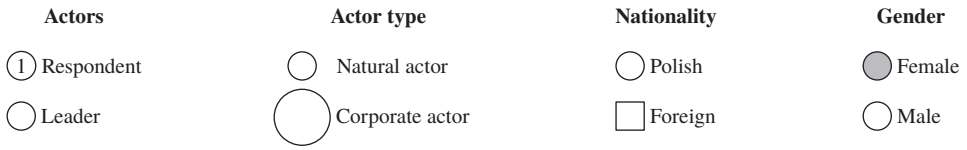
The fragment provides information about gender and shared affiliation of two collaborators, the control of research funds and authority within the group (categories from coding schema 1). On top of that, the fragment provides information about meeting places (a category from coding schema 2).

As a result, two sets of data were obtained. The first one of more quantitative nature with information about the structure of collaboration graph (who collaborates with whom) and categorised characteristics of collaborators. The second data set of a more qualitative nature with broad and less precise information about collaborators and more general opinions about scholarly collaboration, which helps to understand collaboration strategies. The second data set is used, among other, to explain differences between structures of collaboration graphs obtained from the first data set.

The next section contains several illustrations of collaboration networks. On these illustrations persons' attributes are shown with vertex colors, frame, and shape (e.g., gender, leadership, or nationality). Affiliations to common research groups, grants, or institutions are shown with a groups of vertices surrounded by a solid black band. Finally, the authority-based relations are indicated with curved arrows pointing from subordinates to superiors. Figure 1 summarizes all the symbols and colors used. Analysis and visualization of collab-

Figure 1

Legend to figures in section "Results"



oration networks was performed using R (R Core Team 2015) and package 'igraph' (Csardi and Nepusz 2006).

Results

Many scholars emphasize that a well-designed collaboration is the most beneficial form of work for a contemporary scholar. Building a right team can lead to synergy, and it is profitable for all working parties.

Collaboration, collaboration, collaboration. Exchange of experiences, exchange of knowledge. A lack of repetition. We don't always know if a particular issue was tackled or not. It is impossible to check it, even with the Internet. Collaborators have to be open. As I mentioned, working with those who can't see beyond the end of nose, will bring nothing. [Social Scientist]

If we know the same things, if we can do the same things, [working together] *has no sense. The complementarity brings the best results. I can do one thing, you can do something else, and this is our problem. Let's solve it together*. [Natural scientist]

The conviction about the benefits of collaboration encourages more scholars to engage in collaborations, including scholars from traditionally non-collaborative disciplines. The increasing popularity of collaborative work brings more diversity in forms and structures of collaboration and reshapes previous notions popular in collaborative research.

Simultaneously, scholars point out that the balance between collaboration and competition is the main driver for scholarly development. Competitors generate additional motivation and provide a benchmark for academic achievements.

When I think about our experience from last months… If it were not for the pressure and the breath down our necks, I wouldn't have pulled an all-nighter. I'm not sure if it contributed a lot. No, for sure it did. It looks like we did something cool in our work. [Natural Scientist]

I would say that collaboration is the main driver. However, it's hard to say what would it be without competition. The progress wouldn't be so spectacular. A little bit of competition gives an extra impulse. So we have to do things faster. (…) *When we compete, when someone is doing something similar, we have to tense up ourselves* (…). *Competition speeds things up, but collaboration provides benefits and makes our work better in qualitative terms*. [Natural Scientist]

(…) *competition works like this. I sit here and look at my colleagues from other countries. And you know, a half of them has ERC funding. I say to myself: Organize yourself, write something! So competition on this level, when I want the same things my colleagues have, is stimulating. It helps me not to get lost. But it would be impossible without collaboration.* (…) *I think that the Darwinian story is very strong here, but it is inconsistent with the reality*. [Social Scientist]

Leadership Strategies

One of the important questions is how ties within a network are established and maintained, which might be framed as leadership strategies. The results suggest that some alter-alter ties within a scientific collaboration network are initiated by a team leader. In other words, team leaders manage not only their ties but also ties of his/her subordinates. A strategy of a leader might then even take a form of mediating or brokering the ties between different types of actors: individual and group actors.

Consider the three situations described below which illustrate cases of the direct influence of a leader on collaboration ties of his team members. In all these cases, a leader can increase collaboration with rising density of the network or intensify competition by preventing collaborations to develop.

In the first case, a leader of a team of natural scientists forestalled collaboration between lab members allowing for only a small number of micromanaged co-authorships. The respondent—natural scientist I—was a member of the group.

In our lab everyone had his own project and was doing it individually. Eventually, after the project had finished, it could become a part of a greater whole, so that the publication could be made with a larger group of people. But I can't say that they are my collaborators at this moment because we were doing the research separately. And this division of responsibilities was a decision of the lab leader. (…) *we talked,* (…) *something like: "okay, if you need samples for you need them to be fresh, I will make it two days earlier."* (…) *Our leader cares about keeping interactions between us as weak as possible*. [Natural Scientist I]

(…) [Meetings] *should take place in every group. Some seminars or something like this. In our field, it's quite normal that we have seminars, where we present our results in front of the whole group. And there is a critical opinion or some remarks to the effect that "Hey, why is it so? Maybe we should make something else here?". In our group, we are isolated to make us unaware what the other person is doing. Moreover, despite some our personal, let's say—sympathies, or something like this, one necessarily spends less time with these people.* (…) *earlier this group looked a little different. They are still my very close friends—the people who were here earlier and finished a few years ago.* [Natural Scientist I]

The second case shows a situation in which a team leader treats his team as a single multi-person actor. The leader encourages the formation of collaborations with third parties by acting as a group representative. When the actual collaboration starts, the whole group is involved.

The team leader describes her team ties with external collaborators:

We collaborate, we have a few national collaborations. Two of them are functioning lively. One of them is with City X, with Professor Y, who is dealing with proteins (…)*. The second* [collaboration] *is typically synthetic, with the man from City A, who is using our expertise in another discipline. He makes compounds; we make something… We also have a collaboration—the biological one—with, for instance, Professor B from University Y, from the US. We send samples for analysis to the lab in the US. But I consider this to be a scholarly collaboration of the kind: we do our job, and they do theirs.* [Natural Scientist II]

The team consists of the team leader and four Ph.D. candidates. The first description is about collaboration structure, and it's institutional setting. The collaboration structure is filled with information about particular collaborators. When collaboration with third-parties are discussed, the leader talks only about the team collaboration ("we collaborate," "we do our job"), not about individual team members. Therefore, the collaborators become

structurally equivalent (Lorrain and White 1971). A team member can be replaced with a new collaborator without a threat to undercutting external collaborations because the team is a part of the collaboration and not a particular team member.

On the other hand, leader's network strategies may rely on a particular team member to mediate group-to-group collaboration. The case of natural scientist III provides an example. The team leader bridges a tie between the collaborators and third parties. He attempts to establish collaboration with a foreign university. They planned to prepare a proposal for funding, but it required a staff exchange. One of the Ph.D.'s from Polish team was selected, but due to some personal issues he decided not to go. As a result, whole collaboration was on hold with low expectations to be developed for the future.

Recently one of my collaborators has switched teams, the one who was a doctor (…). *I had such plans! Because I've collaborated with my colleague from the States, from University K, on carbon nanotubes, on electron spectroscope. But something was not ok for the guy, because of family reasons he didn't want to go. It was a condition: he goes to the US… We were about to apply for a grant and… We even had, for instance, common conference proceedings.* [Natural Scientist III]

The leader also tries to appoint multiple team members to one collaboration. This strategy provides stable group-to-group ties, but it requires engaging more resources.

They deal [team at University T]*, among other things, with pharmaceuticals and they asked me to make a model* (…) *and, when the opportunity arises, to test our technique* (…). *Even our Ph.D. student—my Ph.D. student—went there, spent some time. He was there on two short internships; we also paid a visit.* [Natural Scientist III]

Location and Academic Degree

Below we look into organisation-level factors and individual-level factor that, as we have argued in section 2, might influence the structure of collaboration networks of individuals.

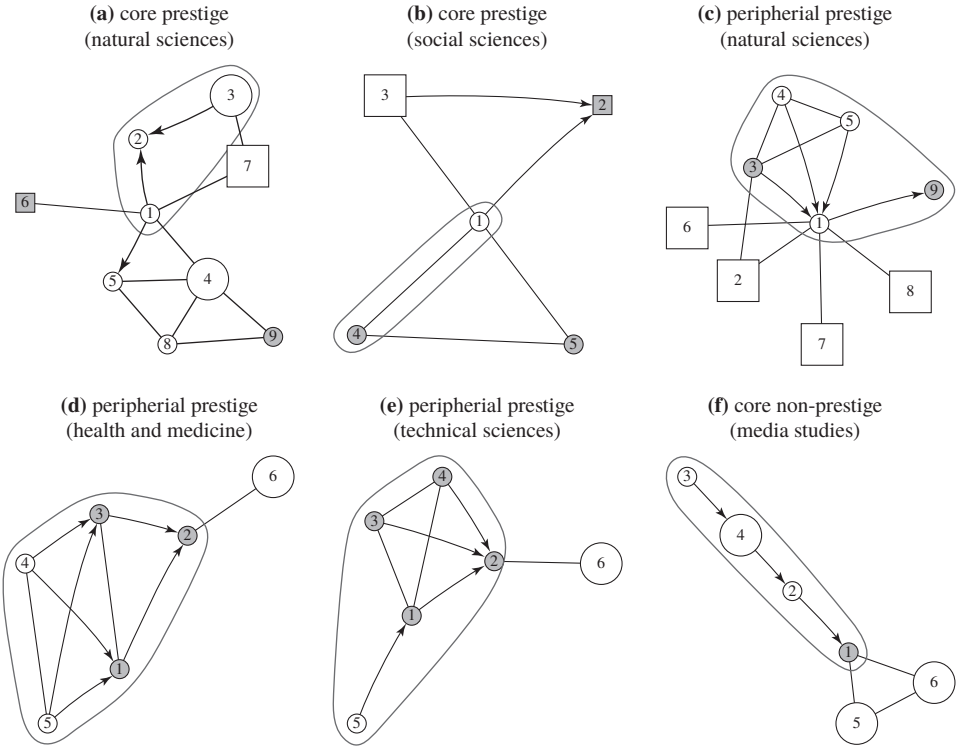
Core vs Peripheral Institutions

Two factors influence a structure of whole ego-networks: a location of an institution (core vs. peripheral) and its rank (according to the official government 3-rank classification). Scholars working in core located and high-ranking institutions (Figures 2a–b) have bigger external collaboration networks, including international collaborations. Scholars from more peripherally located, but high-ranking (Figures 2d–e) and mid-ranking, but core located (Figure 2f) institutions tend to have less developed external collaboration networks. They collaborate mainly with scholars working at the same institution. For example, the collaboration network of a Ph.D. candidate in natural sciences at the core located and high-ranking institution (Figure 2a) is well developed. Apart from institutional collaboration marked with the green background, the scholar also collaborates with a different institution from the same academic center. She also has experience with international collaborations. On the other hand, a Ph.D. in health and medicine studies from peripherally located high ranking institution has only one external collaboration. Both scholars work in highly collaborative disciplines. However, only the natural scientist has been able to build external collaboration network despite being less advanced on the career path in comparison to the health and medicine scientist.

Furthermore, scholars working at core located, but mid-ranking institutions can also struggle with building external collaboration networks. A good example is provided by

Figure 2

Location and core/periphery



a comparison of two social scientists: A—from high-ranking (Figure 2b) and B—from mid-ranking university (Figure 2f). The first one is formally more advanced in his career. He was habilitated several years ago, while the second was just about to become habilitated. The latter has indicated two sub-groups within her collaboration network. The first sub-group was built upon a relation with her Ph.D. supervisor and has been continued since. This sub-group is international. The second group is local but still has members from different institutions. Both of these groups are organized skill-wise. The social scientist B describes her first collaboration sub-group:

(…) *I have a permanent collaborator, my ex-supervisor. He lives in the* [Country A]. *I also have a network of people from different countries, collaborators from* [Country B], [Country C]. (…) *There are also other scholars. Some of them were his* [the supervisor] *Ph.D.'s as well, but not all of them. They are also his friends. I met some of the others from the* [Country C] *when I was in* [Country D]. *They were there in an exchange program.* (…) *There are also his collaborators from the* [Country A]: *Ph.D. students from previous university, former Ph.D. students.* [Social Scientist B]

The second sub-group was described:

(…) *it was my colleague's idea, and he invited me to join. He is the leader. I'm a team member.* (…) *We also invited one of my colleagues from a different university because we wanted to do experiments and I knew that he was good.* [Social Scientist B]

The initial fuel for some of the ties in both of these networks was the institutional setting (e.g. being a supervisor), but collaborations also flourished afterwards. The Social Scientist B does not limit her collaborators to the most accessible colleagues from her institution but looks for those fitting her the most in terms of skills.

The second case (Figure 2f) provides an example of a collaboration network comparable in size to the network of the Social Scientist B. The respondent is a leader of a small unit, which he is trying to use as a premise to build collaborations. Consequently, his collaboration network consists of scholars from the same institution (marked with a green background). The formation process was described as follows:

We are different in our unit. We differ a lot. We have different characters, and we have different experiences. (…) *So we are eclectic, and we should try together to extract something from it. I support the idea that we should extract something together. We can do stuff separately as well, but we should focus on coming up with something for the whole team, something we could use as our 'trade sign.'* (…) *So we are going to apply for a grant in the spring* (…)*. Do it together.* [Social Scientist A]

He continues:

It's good when a team (…) *shares one concept, one that is interesting to all members..* (…) *a team has to have one idea. We need one direction to build something together. When everyone is promoting his own idea, a leader can't build anything upon it. He may use a 'dominant' and say: I am the boss, and we do this. But I was lucky because my team offloaded. My job is to find a single thread, which would connect us. The thread is inconsiderable, but it is there.* [Social Scientist A]

The respondent has no other ties he could potentially use to build scientific collaborations based on shared interests. He is limited to colleagues from his unit, who have diverse interests and, in consequence, he struggles to find something they have in common.

The peripheral location of an institution and its negative impact on external collaboration networks might be moderated by mobility. The difference between the collaboration networks of mobile and not mobile scholars from high-ranking but peripherally located institutions is visible in comparison of Figures 2c and 2e. Figure 2c represents a collaboration network of a Ph.D. with substantial mobility experience. She received her Ph.D. from a Polish academic institutions. Afterward, she did her post-doc abroad and relocated back to Poland but to a different, more peripheral city. She kept her collaboration partners from earlier stages of her career, and she has learned how to build new collaborations. The respondent describes her ties from previous institutions:

[My collaboration networks] *include several people from my current institutions and several people from my post-doc, who are my permanent collaborators. It's good that we maintain these collaborations.* [I collaborate] *also with some people I met even earlier during my Ph.D. I did it fifty-fifty in Poland and Germany, so there is much collaboration with Germany.* [Natural Scientist]

Figure 2e represents a collaboration network of a scholar from peripherally located high-ranking institution, but without any substantial track of mobility. He has no immediate external collaborators. The description of his collaboration network is as follows:

My closest collaborator is my teacher. I started working with him during my Ph.D. We have been collaborating ever since. He has built a team I am a member of. Now there is also my Ph.D. candidate, so there is some hierarchy. The team consists of his students, precisely one student and one Ph.D., who has joined our team. Everyone has his area of responsibility. [Technical Scientist]

The respondent has been habilitated, but he has never worked in a different team. For some reasons he has not developed any other collaborations outside his institution, although he, his team and the department have significant scientific achievements.

Academic Degree

Traditionally in Polish Academia scholars were expected to achieve formal recognition of independence, for example, habilitation in order to to establish a research team. To be a Ph.D. supervisor a scholar had to have at least the habilitation title. The most recognized and generous funding streams were also restricted to a smaller group of professors. We conjectured that the leader's academic degree would influence the structure and size of the whole ego-network.

However, the data does not support this hypothesis. More in-depth analysis of the Ph.D.'s (without habilitation) collaboration networks suggests it might be a result of the ongoing reform of Polish Academia and its funding. The Ph.D.'s leading teams usually have an independent source of funding substantial enough to recruit and maintain a group of collaborators. Several governmental funding streams are dedicated to Ph.D.'s up five years after obtaining the degree including streams to build a research team. There are also funding streams open to all regardless of the academic degree, where Ph.D.'s can compete with more advanced scholars. Non-government institutions, e.g. The Foundation for Polish Science offer several types of funding stream available to Ph.D. The funding scheme encourages young scholars to establish their own research teams. However, a profile of Ph.D.'s with their teams is particular. Usually, they have been mobile, obtained Ph.D. abroad or went abroad for a post-doctorate training. They have more than one source of funding. Financial independence also gives a relative independence from local institutional hierarchies, but the process of establishing a new team is usually supported by someone from the local scholarly community. This points to an important role of having access to diverse funding opportunities, namely, the enable overcoming rigid hierarchies in scholarly communities.

For example, the natural scientist II (Figure 3c) has benefited from several of mentioned funding schemata. After post-doc abroad she has received special funding for Polish scholars working abroad and willing to come back to Poland. Later on, she has also applied for funding to built her research team. Moreover, she is also a part of European funding scheme aiming to establish a scientific network, providing funding for conferences and meetings. The Europen funding scheme also provides some additional funds for team members. The scholar describes her experience with funding:

It was absolutely beautiful [homecoming funding]. (…) *I spent part of the money on my salary, because, let's face it, the Ph.D. salary is what it is. I spent the second part of the money on short study visits at my new university just to work together, and to go to a conference, and to buy several things like computers, laptops and so…* [Natural Scientist II]

The scholar had to refer only to the funding institution, which was independent of the university. It gave some independence from local hierarchies. The additional funding was dedicated to Ph.D.'s for building a research team.

We wanted to build a team. The team is not very big. The team that works here consists of four people, but we also have external collaborators from Poland and from abroad. [Natural Scientist II]

The process of building the team is supported by additional European funding:

There are also European funding streams facilitating collaboration. Several very committed people applied to the European Union to get funding and build collaboration. These are mainly the Dutch, Belgian, and Italians, but also people from other European countries, including Poles. Thanks to that money we can go to some conferences or workshops, and they fund it. It helps us a lot to overcome limited resources in our team grant. To be honest, in our team grant we have money only for two conferences per person. It is not a lot. I mean I think it is not a lot. Particularly for young scholars, who must go to conferences, to listen to lectures, to do some networking, to build some contacts. Two international conferences a year are not enough to do that. [Natural Scientist II]

All mentioned sources of funding were granted by the external institution and, therefore, they do not depend on local hierarchies and dependencies, including formal seniority.

The social scientist (Figure 3b), who is in fact now after habilitation, started building his team after coming back as a Ph.D. to one of the Polish universities. He has enough funds to cover his and his team salaries. Therefore, he is independent of a department board. He describes his institutional embeddedness:

We have here a badge on the door saying it is my team. A part of my team paid from my grants sits there. However, I don't have my own lab or unit. There is this formal organisational structure reflected in units. I don't have that. I didn't feel like it. I'm affiliated with another unit, but colleagues from my unit do something else. They use a different method, and their area of interests is somehow different. I was fetched up here. Our dean pushed me in here. The dean, as she said, wanted me here. Or I wanted to be here, and she agreed. So there is no formal unit, but usually there is some formal organization. He continues: *We have poor mobility in Poland. People inherit their subjects. Once you start your Master in one place, you won't change the place.* (…) *I think it is a huge problem. That's why I decided to give lectures for students. I do it not because I have to. I have many grants, so I can cover my whole salary without taking any teaching obligations. But, I have to attract students because I spent so many years abroad and no one knows me.* (…) *I hope that it will build my reputation among students.* [Social Scientist]

On the other hand, being totally independent is impossible, and some compromises have to be made. The social scientist, who obtained his Master and Ph.D. in two different fields, decided to become habilitated in the research field consistent with his current department. The change of field was—at least, to some extent—motivated by peer pressure.

I was in many awkward situations. There was one situation when the fact I'm not trained in [my department's field] *was used against me. That's why I decided to do habilitation in the same field because here not everyone accept the fact that I'm trained in a different field.* [Social Scientist]

The third case illustrates the process of building a team within the home institution (Figure 3a). The respondent did her Master and Ph.D. and continued work in at the same department. She has a boss, who is a unit leader, but she controls several research projects, which gives her some independence.

I have a boss. He is a unit leader (…) *. We have EU projects* (…) *and I do it with two of my Ph.D.'s.* (…) *I decide what will be done, where should we go with our work* (…). *I'm a team leader, I make decisions, come up with projects, ideas* (…). *Two Ph.D.'s work at the laboratory, they do analysis* (…), *they do literature reviews.* [Natural Scientist I] She describes collaboration structure with some additional details: *We are not formally a group. Both of the Ph.D.'s work with me. One of them works in my grant. But it is only a formality. They worked in our department in my boss' unit.* [Natural Scientist I]

The history how Ph.D.'s were hired brings more light on the department dependencies.

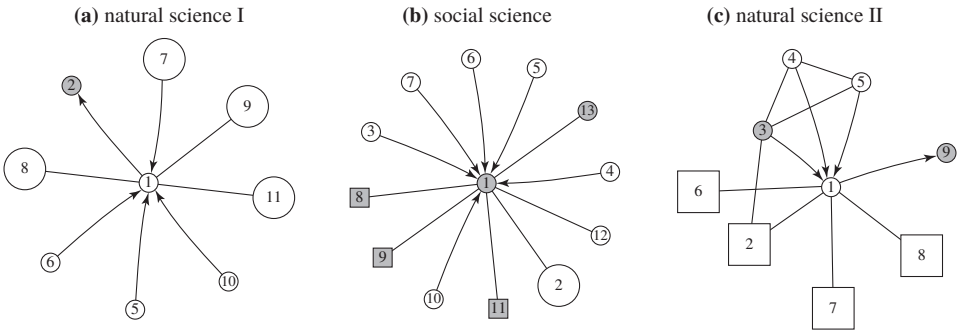
When A. finished her Master I was looking for someone to help me with my work. I went to the director and asked to assign me a spot, so I would be able to hire someone. The director was kind enough, and he decided that I deserve

to have a collaborator. And, I hired A. We had problems with that. At first, she was only part-time. It lasted several months. After that time when one professor was not with us anymore, we could have hired her full-time. It was a bit different with B. I supervised A.'s Master, and she stayed with me to continue her work. I didn't supervise B.'s Master. The professor [the unit leader] *was her supervisor. I had a grant, and I was looking for someone* (…)*, but I didn't want to hire anybody. B. decided to do Ph.D. here, and I had someone to work. I was very happy.* (…) *A. worked on a project* (…) *B. has been working on the project for two years. Maybe a year and a half, because she was hired for a while as an intern from a job center.* [Natural Scientist I]

The institution requires many negotiations concerning who, how, and for how long will be hired. In contrary to the previous case blurred organizational division, it maintains traditional hierarchies. Moreover, smaller independence in building the team is rather a result of existing institutional and formal dependencies to a greater extent than a scarcity of resources.

Figure 3

Ph.D. Within a Team



Discussion

The study reported in this article was motivated by the need to take a more careful look into collaboration in science on three levels: actors, relations, and networks. We have argued in the introduction and literature review that such a closer, more detailed analysis is necessary for making progress in understanding social processes of competition and collaboration operating in science. Among other things, it should enable identifying mechanisms that affect incentives for individual scholars to collaborate.

We have argued that there are both natural persons and corporate actors, who should be recognized as different types of actors in collaboration structures. We also argued that we can indicate a factor affecting the way collaboration ties are established within ego-networks and individual-level and organisational-level factors shaping the structure of ego-networks.

We propose that leadership strategies provide explanation for establishing some collaboration ties within an ego-network. Three basic strategies undertaken by leader were identified: (1) controlling and limiting collaborations between collaborators, (2) building collaboration around structural team positions, which are occupied by different collaborators, and (3) building collaboration around one or more collaborators. Adopting one of

them has major consequences for developing robust collaboration ego-networks because some collaborators might serve as stabilizers for looser relations by e.g. staff exchange. The collaboration structure is more resilient if a collaboration with the third party engages more than one collaborator, but this strategy also requires more resources.

Location of home institution or its rank have influenced the structure of ego-networks. Scholars working lastingly at more peripheral and lower-ranking institutions have less developed collaboration networks beyond local collaborations. Since collaboration networks are an important channel for disseminating information, skills, and knowledge, being less connected impels yet more peripherally situated scholars to be on the edges of global collaboration networks. The analyzed cases indicate that collaboration networks are associated more with scholars than with institutions. In consequence, if a scholar moves from one institution to another, s/he keeps, at least, a part of collaborations. The small mobility hinders the development of collaboration networks especially among scholars from peripheral institutions. It results in deepening a division between core and peripheral institutions affecting both individual careers and institutions.

Some of the results indicate that factors recognized previously as focal in shaping collaboration structures including academic degree have only limited impact. There are two main reasons for this irregularity. The reform of education system in Poland has opened opportunities to advance the career of younger scholars, to build their team, and to receive independent funding for research. Several funding streams were dedicated to young scholar up to 5 years after Ph.D. Moreover, applying for several other streams of financing do not require having a primary investigator with habilitation. It opened new paths for Ph.D. with significant achievements, but without a higher academic degree. The changes were also supported by additional funding streams from the European Union. However, breaking out from existing hierarchies is easier for scholars new to the institutions. Having independent funding is not enough to gain significant power over collaboration structures.

The presented study contributes to research on collaboration networks in science in several ways. Firstly, the analysis shows that some factors traditionally recognised as focal for shaping collaboration processes might be secondary in certain social contexts. For example, the independence in research is influenced more by access to funding than by having appropriate scientific degree. Secondly, collaborations within one ego network might be of different nature: some of them are more personal and lead to individual relationships but some are collaborations with corporate actors where individual relationship is of secondary importance. These type of actors might be represented by more than one person. Persons representing a corporate actor might change over time but the nature of collaboration stays the same. Thirdly, the presented contribution is based on a novel mix-methods approach, where the object under study are a collaboration networks extracted from qualitative interviews. The differences in collaboration structures are interpreted with detailed information obtained from interviews. The presented approach contrasts with more traditional qualitative approaches focusing on narratives. The main advantage of a qualitative study, like the one reported in this article, is depth in providing detail on individual observations. At the same time, it has obvious disadvantages: lacks generality, statistical power, and representativeness (in statistical sense). One of our goals for the future is to use the results obtained in this study for formulating hypotheses that can be tested with quantitative data.

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Appendix

Basic information about the respondents in the sample.

ID	Gender	Degree or title	Field of science	Academic center
1	woman	Ph.D. with habilitation	hard sciences	central
2	woman	Ph.D. with habilitation	the humanities	peripheral
3	woman	Ph.D.	the humanities	peripheral
4	woman	Ph.D.	social sciences	central
5	man	Ph.D.	technical sciences	peripheral
6	man	Ph.D.	health and medicine	peripheral
7	man	Ph.D. with habilitation	technical sciences	peripheral
8	woman	Ph.D.	natural sciences	peripheral
9	man	Ph.D. with habilitation	veterinary and agricultural sciences	central
10	man	Ph.D. with habilitation	health and medicine	central
11	man	Ph.D.	social sciences	central
12	man	Ph.D. with habilitation	hard sciences	central
13	man	Ph.D.	health and medicine	central
14	man	Ph.D.	natural sciences	central
15	man	Professor	hard sciences	central
16	woman	Ph.D.	social sciences	central
17	man	Ph.D. with habilitation	social sciences	central
18	man	Ph.D.	veterinary and agricultural sciences	central
19	woman	Ph.D.	technical sciences	peripheral
20	man	Ph.D. with habilitation	social sciences	peripheral
21	man	Ph.D. with habilitation	hard sciences	peripheral
22	man	Ph.D.	technical sciences	peripheral
23	woman	Ph.D.	hard sciences	peripheral
24	woman	Ph.D.	the humanities	peripheral
25	woman	Ph.D. with habilitation	social sciences	central
26	woman	MA	social sciences	central
27	woman	MA	hard sciences	central
28	woman	Ph.D. with habilitation	hard sciences	central
29	woman	Ph.D. with habilitation	technical sciences	central
30	man	Professor	hard sciences	central

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Biographical Notes

Michał Bojanowski, (corresponding author)—sociologist and assistant professor at Department of Quantitative Methods & Information Technology at the Kozminski University. His main research interests are conflict and co-operation and their understanding using theories and methods of game theory and social network analysis. He published on modeling co-evolution of behavior and networks, measurement of segregation in social networks, and formation of inter-firm alliances in *Social Networks* and *Journal of Mathematical Sociology*. His other interests include mathematical sociology, social network analysis, data analysis, computational modeling, and statistical computing.

E-mail: mbojanowski@kozminski.edu.pl

Dominika Czerniawska—graduated from sociology and history of art at University of Warsaw. Since 2010 she have been working in the Interdisciplinarcy Centre for Mathematical and Computational Modelling, University of Warsaw, where she has been engaged in several research projects concerning mainly research on transformation of Polish scholarly community as well as the impact on social and economic life. She is a Ph.D. candidate at The Robert T. Zajonc Institute for Social Studies, University of Warsaw. Her doctorate thesis, focuses on changes in Polish scholarly community during the last 25 years and its relations with institutional systems like government agencies, market and industry.

E-mail: dominika@czerniawska.com

Wojciech Fenrich—graduated from sociology and philosophy at the University of Warsaw. Currently works as an analyst in the Interdisciplinarcy Centre for Mathematical and Computational Modelling at the University of Warsaw. His research interests are topics such as social aspects of scientific publishing and open science.

E-mail: w.fenrich@icm.edu.pl