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Scientific collaboration in Russian universities before and after the excellence initiative Project 5-100

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Abstract

Changes in patterns of collaboration between Russian universities after the commencement of the Russian university excellence initiative (Project 5-100) are studied in this paper. While this project aimed to make leading Russian universities more globally competitive and improve their research productivity, it also happened to increase their cooperation. An analysis of affiliations and the co-authorship networks was conducted to explore scientific collaborations between and within the participating universities. Such analysis facilitates the investigation of the number of collaborations with other organizations, both domestic and international cooperation, and disciplinary differences. By analyzing the co-authorship networks, the position of universities in the academic network and the structure of collaborations among the participants were examined. A sample of 30 Russian universities, including participants in Project 5-100 and a control group of institutions with similar characteristics, was used. After joining the project, the participating universities increased both their cooperation with each other as well as with foreign universities and research institutions of the Russian Academy of Sciences, especially in the high-quality segment. At the same time, the collaboration patterns of non-participating universities did not change significantly. The centrality of Project 5-100 universities in the global academic network has increased, along with their visibility and coupling in the national network. The historical division between university and academic sectors has diminished, while the participating universities have started to play a more important role in knowledge production within the country.

Keywords Social network analysis · Scientific collaboration · University excellence initiative · Co-authorship network · Blockmodeling · University · Russia

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Introduction

Scientific collaborations increase access to knowledge and funding (Rawlings and McFarland 2011), improve the quality of research, and reduce research costs (Abramo et al. 2009; Bikard et al. 2015), while also stimulating the economic development of countries (Sonnenwald 2007). The benefits of collaboration, along with technology development, have encouraged scientists from different universities, regions, and countries to communicate with each other (Wagner et al. 2015; Larivière et al. 2015; Ribeiro et al. 2018). Besides the benefits, collaboration also incurs costs like organization and communication expenses and the decline of the formal productivity of individual scientists (Bikard et al. 2015). Nowadays, the tendency and types of scientific collaboration, the contribution of collaboration to knowledge production, and the factors which facilitate or inhibit collaboration are the subject of many studies.

Scientific collaboration may be distinguished by the affiliation of scientists to one or many disciplines, organizations, regions, and countries. Collaborations can thus be inter-institution, intra-region, multidisciplinary, cross-country, etc. The growth rates of scientific collaboration as well as the benefits and costs have national and disciplinary specifics (Leahey 2016). For example, multidisciplinary papers have more citations than papers from a single field (Ni and An 2018). The collaboration cost is less if scientists work in one organization (Bikard et al. 2015). Academics from China and Taiwan have a below-average level of international collaboration, with the highest levels being observed in smaller countries like Cyprus, Vietnam, and Qatar (Elango et al. 2017).

Scientific collaboration is studied in several ways: by a survey of scientists (e.g., Iglič et al. 2017), by co-authorship of publications (e.g., Ferligoj et al. 2015), or even by analyzing hyperlinks on university websites (Barnett et al. 2014). Co-authorship is a commonly used measure to study scientific collaborations because it is a sufficiently simple and objective way to gauge scientific cooperation. The main drawback of co-authorship as a proxy for collaboration is that it does not reflect all dimensions of collaboration occurring between scientists (Ponomariov and Boardman 2016). Co-authorship's big advantage is that it reflects the real output of research collaboration. Analysis of co-authorship not only reveals the dynamics of collaboration, but investigates the structure of collaboration through a co-authorship network (Newman and Girvan 2004; Kronegger et al. 2012).

The co-authorship network of universities represents aggregated collaborations of scholars from different organizations, although these collaborations sometimes consist of one person affiliated with several organizations. The structure and principals of scientific collaboration on an individual level are partly valid for scientific cooperation between universities (Barnett et al. 2014). Although universities and institutions are macrostructures, their collaboration motives can also be determined by economic factors and public policy.

Government excellence initiatives exert a significant influence on the collaboration patterns of universities. These initiatives stimulate and regulate educational and research activities at universities (Altbach and Salmi 2011). Enhancing research activity and inducing scientific collaboration with other organizations, including foreign ones, is often the purpose of such programs (Zhang et al. 2013; Yonezawa and Shimmi 2015; Möller et al. 2016; Shin 2009).

Russia is no exception. The Russian university excellence initiative Project 5-100 was launched in 2013 with the aim of making leading Russian universities more competitive in the global academic market. The project's name reflects its main goal: at least five participating universities in Project 5-100 are to appear among the world's top 100 universities in 2020. The project provides funding for Project 5-100 universities, which depends on annually monitored key indicators. A crucial criterion for staying in the project is publication activity, which includes the number of publications in international scientific journals contained in international databases, and the number of citations.

In the first years of Project 5-100, universities increased their publication activity, including the number of high-quality publications (Turko et al. 2016; Poldin et al. 2017). Agasisti et al. (2018) found the project has had a positive effect by way of developing research activities within universities. Another study (Guskov 2018) showed that, after joining Project 5-100, universities have also changed their scientific collaboration strategy to increase the number of publications. Moreover, since 2013 the number of author affiliations and number of papers written in collaboration with other organizations have increased in the Project 5-100 universities (Matveeva et al. 2019).

These results reveal that the project encourages Project universities to intensify their collaboration with other organizations. To understand the role played by Project 5-100 in developing a new scientific collaboration culture among the universities, it is important to consider the features and academic traditions of Russia's research system. In the Soviet period, the research system was essentially isolated from the world academic market. Moreover, domestic academic mobility was neither obliged nor a priority and therefore was not massive (Ryazantsev et al. 2019). Despite the rapid rise in scientific mobility and creation of research collaboration opportunities in modern Russia, the rate of scientific collaboration in the country remains quite low (Elango et al. 2017; Artamonova and Demchuk 2012).

Another feature of Russia's research system is the presence of the Russian Academy of Sciences (RAS), along with several research universities. These universities mostly concentrate on pedagogical activity while the RAS focuses more on scientific research. In the period since Project 5-100 commenced, Project universities have significantly increased the number of publications written in collaboration with the RAS (Ivanov et al. 2016; Mazov and Gureev 2017; Guskov 2018). However, most Russian highly cited publications are co-authored with researchers from foreign institutions (Pislyakov and Shukshina 2014).

Namely, Project 5-100 was implemented in the Russian research system characterized by relatively low scientific mobility and the presence of a large research organization, the RAS, along with universities. In this context, the following questions emerge: How much did the scientific collaboration of the Project universities change after Project 5-100 was launched? Who are the collaborators and how do these collaborations affect the publication quality? In this study, we investigate how collaboration patterns changed in two groups of Russian universities once the project was underway. To that end, we analyze the dynamics of several solo publications, the number of papers written in co-authorship with other Russian academic organizations, the RAS and foreign institutions. We also look for disciplinary and quality differences in the collaboration patterns. In addition, we study the position held by universities in the scientific co-authorship network and the stability of the clusters of universities that are obtained.

This study investigates scientific collaborations in two university groups before and after Project 5-100 commenced. We examine the dynamics of the collaborations, with whom the universities prefer to work together in various areas of research and quality segments, and the position of the universities within the academic co-authorship network.

Data and methods

The study's main goal of the study is to analyze patterns of scientific collaboration of two groups of Russian universities: universities participating in Project 5-100 (here in after: the treatment group or Project universities) and universities not included in Project 5-100 (the control group) with respect to the periods before and after that project. The first 3-year wave of Project 5-100 commenced in 2013. Therefore, we added 3 years prior to it being launched (2010–2012) and 1 year after it (2016) since many publications written between 2013 and 2015 can be published in 2016. Our analyses rely on bibliographic data concerning the selected Russian universities in the period 2010 to 2016.

The total number of publications from 2010 to 2016 attributed to the selected universities' profiles in Web of Science (WoS) (Science Citation Index Expanded, Social Sciences Citation Index, document types "article" and "review") was used because publications included in WoS are primarily considered for evaluating the performances of the Project universities. We did not use data from the Arts & Humanities Citation Index (A&HCI) since this index is not included in Journal Citation Reports (JCR) and thus publications from this index do not have the journal quartiles we use in our analysis. Further, disciplines from the humanities are much less covered in WoS than other fields (Aksnes and Sivertsen 2019), although this might explain the pure data in A&HCI. The Project universities in the treatment group together have only 521 publications in A&HCI for the whole analyzed period, while for the control group have 538.

Conference proceedings are unlike journal publications in that they are frequently cited (Zhang and Glänzel 2012), have no quartiles estimated in WoS (they rely on another rating system), and often contain preliminary results that are later republished in a journal (double-counting problem). Yet, proceedings play an important role in scholarly communication. In some disciplines (e.g., computer science), results are typically published as a proceedings paper. Accordingly, such publications should be analyzed separately and were excluded from our analyses.

Since the study aimed to analyze the dynamics of top publications (Q1) and the lowest quality of publications (Q4) in the two Russian universities groups, the number of publications in journals of the highest (Q1) and lowest (Q4) quartiles according to their journal impact factor (JIF) was used. The highest journal quartile (Q1) means a journal is found in the top 25% of a certain subject category. Especially top publications (Q1) from WoS have the biggest impact on the Project universities' evaluation.

Research areas were classified according to WoS categories: Arts & Humanities; Life Sciences & Biomedicine; Physical Sciences; Social Sciences; and Technology (https://images.webofknowledge.com/images/help/WOS/hp_research_areas_easca.html).

One study task is to compare patterns of collaboration among the selected universities before and after Project 5-100 was launched. Comparison of the treatment group and control groups helps understand how treatment group dynamics vary from the dynamics of other Russian universities. Therefore, several criteria were applied to the universities in the control group. First, universities from the treatment and control groups should have comparable bibliometric indicators at the beginning of Project 5-100. In this study, since we are analyzing scientific collaboration as measured by the co-authorship of papers, indicators revealing universities' publication activity are vital. We compared the number of publications, its distribution by research fields, the share of publications in journals of the Q1 and Q4 quartiles and the share of publications with one or more citations according to all publications. The second criterion was the geographical proximity of the groups. The control group universities should be located in the same federal districts as the Project universities. Third, the universities' research profiles should be similar. For example, this criterion meant we did not select medical universities. Bibliometric indicators were also used while selecting universities for the treatment group, which includes all the universities selected in the first wave of Project 5-100.

We established scientifically robust control groups since the studied universities are also leading Russian universities with ambitions to rank in the top 100 world universities. Therefore, the control group includes two big Russian universities with high publication output (MSU and SpbGU). Another important control group criterion is the annual presence of Q1 publications because we are examining differences in the quality of the collaboration patterns. It is thus not surprising that five universities entered the control group during Project 5-100's second wave at the end of 2015. These universities received Project 5-100 funding only in 2016, meaning we may assume that participation in the project still had no particular influence on their publication and collaboration activity in 2016.

Finally, Table 1 presents the selected universities in the treatment and control groups along with their abbreviations used in the blockmodeling analysis (see Figs. 6 and 7).

Before Project 5-100 started in 2013, on average the control group had more publications than the treatment group, especially in the Life Science & Biomedicine field (Table 2). At the same time, the share of publications in Q1 journals was higher in the treatment group. Prior to the project starting, both groups of universities enjoyed approximately the same share of publication citations (Table 5 in the "Appendix"). The low values for the share of cited publications in both groups in the last few years may be explained by the fact that citations need time to emerge.

Despite the scientifically strong universities (MSU and SpbSU) in the control group having a high number of publications for the entire period under study, we observe that once Project 5-100 was underway the treatment group universities have a higher publication output than those in the control group (Table 2). This situation is seen in all research areas, namely, the Project universities had more publications than the control group universities, and the highest growth in the Social Sciences and Humanities, partly explainable by the small number of publications in these fields in the first years observed (low base effect). Further, the number of publications in Physical Sciences in the treatment group universities also grew significantly. Studies in this field include works prepared on special mega science equipment (like the Large Hadron Collider) and thus necessitate a high level of international cooperation. After Project 5-100 started, several Project universities became actively involved in such studies (Matveeva et al. 2019). Table 2 shows how natural-science data prevails in WoS (Mongeon and Paul-Hus 2016).

Analysis of affiliations

From each publication, information was extracted about the authors' affiliations, number of co-authors, year of publication, research area, and ISSN (International Standard Serial Number) of the journal. ISSN was used to obtain the JIF for each year. All of these data were used to analyze the collaboration patterns of Russian universities. First, all

Table 1 Names and abbreviations of universities in the treatment and control groups

Treatment group	Control group
Far Eastern Federal University ***(FAR EASTER)***	Baltic Federal University ***(IMMANUEL K)***
National Research University Higher School of Economics (***NRU HIGHER)***	Bauman Moscow State Technical University ***(BAUMAN MOS)***
Kazan Federal University ***(KAZAN FU)***	Moscow State University ***(LOMONOSOV)***
Moscow Institute of Physics and Technology ***(MOSCOW I P)***	North-Eastern Federal University in Yakutsk ***(YAKUTSK SU)***
National University of Science & Technology ***(NU SCI TEC)***	Perm National Research Polytechnic University ***(PERM NRPU)***
National Research Tomsk State University ***(TOMSK SU)***	Moscow Aviation Institute (***SU AEROSP)***
National Research Tomsk Polytechnic University ***(NR TOMSK P)***	Peoples Friendship University of Russia ***(PEOPLES FR)***
National Research Nuclear University ***(NRNU MEPHI***)	Siberian Federal University ***(SIBERIAN F)***
Lobachevsky State University of Nizhny Novgorod ***(LOBACHEVSK)***	Saratov State University ***(SARATOV NG)***
Novosibirsk State University ***(NOVOSIBIRSK)***	Southern Federal University **(SOUTHERN F)**
Samara National Research University ***(SAMARA SAU)***	Tyumen State University ***(TYUMEN SU)***
St. Petersburg State Polytechnical University **(StPET POLY)**	St. Petersburg state University ***(StPET SU)***
St. Petersburg State Electrotechnical University ***(StPET ELEC)***	Ufa State Aviation Technical University ***(UFA SATU)***
St. Petersburg State University of Information Technologies ***(ITMO UNIV)***	South Ural State University ***(SOUTH URAL)***
Ural Federal University ***(URAL FU)***	Voronezh State University ***(VORONEZH S)***

publications were analyzed and then Q1 and Q4 publications were analyzed separately to study differences in the quality of these patterns.

1. We initially analyzed the dynamics of affiliations in solo publications; more precisely, the number of affiliations held by one author. Publications with a single author allow us to determine a ‘special’ type of scientific collaboration: when a scientist is working in several organizations. A growing number of affiliations of one author means their publications were partly prepared using the resources of several organizations.
2. The question of with which academic institutions the universities have joint publications was examined next: foreign organizations, Russian universities or organizations, or the Russian Academy of Sciences (RAS). We considered international and domestic collaborations. The Russian research system comprises research universities mostly focused on teaching, a large number of institutions coordinated by the RAS, and other institutions not included within the RAS structure. The RAS has a greater focus on

Table 2 Descriptive statistics for number of publications in total and by scientific field

	2010	2011	2012	2013	2014	2015	2016
Total number of publications							
Treatment group	2981	3532	4188	5366	7554	10,460	11,647
Control group	5445	5547	6168	6278	6982	8208	8833
Technology							
Treatment group	817	1023	1178	1530	2210	3173	3599
Control group	954	957	1015	1217	1409	1767	2080
Physical sciences							
Treatment group	2342	2674	3159	3955	5421	7299	8050
Control group	3825	3995	4334	4285	4727	5387	5812
Life sciences and biomedicine							
Treatment group	224	283	350	567	843	1424	1665
Control group	1119	1063	1281	1394	1600	1975	2022
Social sciences							
Treatment group	33	62	110	127	258	323	459
Control group	118	112	198	145	152	158	274
Arts and humanities							
Treatment group	24	18	37	32	89	114	160
Control group	85	54	81	53	66	110	87

research activities than universities and is the source of the highest number of high-ranking publications (Ivanov et al. 2016). The set of Russian universities or academic organizations includes all organizations, except foreign ones and the RAS. Organizations from this set concentrate less on research activity than foreign institutions and the RAS. This separation allows us to study Project 5-100's effect on the domestic research environment as well as the integration of Project universities into the global academic community.

3. We then looked at the quality of the publications and disciplinary differences in collaboration patterns, by type of publication (all publications, publications in Q1 and Q4 journals) and by research area (Arts and Humanities, Life Sciences and Biomedicine, Physical Sciences, Social Sciences, Technology).

Analysis of the co-authorship networks

We constructed two types of co-authorship networks: the first includes all universities and organizations mentioned in publications of the 30 universities in the sample and the Russian Academy of Science, while the second consists of only the 30 universities (treatment and control group). Neither network type is weighted nor normalized as they are similar in size and their dynamics for the period 2010 to 2016 were being studied.

The first type of co-authorship network takes account of joint publications only among the mentioned organizations and does not consider collaboration outside of these organizations. These co-authorship networks were constructed to analyze the dynamics of collaboration in the two university groups and the change in the positions held by these universities in the co-authorship network. The networks were constructed using the R (R Core Team 2017) programming language.

In the co-authorship networks, the nodes are universities and scientific organizations while the links represent the number of joint publications of two universities or organizations. Here we considered the size of the networks and computed the following: The *diameter,* namely the maximum distance between any pairs of nodes, was calculated using the breadth-first search method (Corneil et al. 2003). The *mean distance* characterizes the distance between network participants. Distances are the lengths of all shortest paths from/to the vertices in the network (Csardi and Nepusz 2006). *Density* Δ shows the proportion of available links:

$$\Delta \equiv \frac{2L}{g(g-1)}$$

where L denotes the number of links and $g(g-1)$ the number of all possible links.

Average degree centrality is the average number of universities with which a university has engaged in joint publications. Highest degree centrality is enjoyed by universities with the largest number of collaborators. Degree centrality shows how a university collaborates with other universities, but does not reflect its position relative to others.

We also constructed a blockmodel of the co-authorship network of the 30 Russian universities to evaluate their structure according to their collaboration patterns in each year. A blockmodel is defined by clusters of equivalent (or as equivalent as possible) universities and the relationships among these clusters. Blockmodeling is an approach for simplifying a bigger network by obtaining a smaller structure.

Several blockmodeling procedures are used to obtain blockmodels. Since a co-authorship network is a valued network (we did not take account of the loops, i.e., publications within a university), we applied the indirect blockmodeling procedure to analyze the change in the co-authorship structure of the sample universities from 2010 to 2016. This approach requires selecting a (dis)similarity measure between two universities and applying a clustering algorithm to calculated (dis)similarities among all pairs of units. Here, it is crucial that the definition of (dis)similarity is compatible with the assumed equivalence between two universities (Batagelj et al. 1992): the dissimilarity measure d is *compatible* with a considered equivalence $\sim$ if for a pair of equivalent universities x_i and x_j it holds

$$x_i \sim x_j \Leftrightarrow d(x_i, x_j) = 0$$

We selected structural equivalence: two universities are structurally equivalent if connected to the rest of the network in identical ways (Lorrain and White 1971). A compatible dissimilarity with structural equivalence is Corrected Euclidean-like dissimilarity (Doreian et al. 2005, p. 181):

$$d(x_i, x_j) = \sqrt{(r_{ii} - r_{jj})^2 + (r_{ij} - r_{ji})^2 + \sum_{\substack{s=1 \\ s \neq i,j}}^{n} ((r_{is} - r_{js})^2 + (r_{si} - r_{sj})^2)}$$

where r_{ij} denotes the number of publications in which there are co-authors from university x_i and university x_j. As we did not consider the number of publications within universities (loops) and since the co-authorship network is symmetric, the first two terms in the above formula are 0.

We then used Ward's well-known hierarchical agglomerative procedure (Doreian et al. 2005, p. 147) to obtain the hierarchical clustering of the universities presented by a dendrogram that allowed us to determine the best partition for the 30 Russian universities and the links between the clusters thereby obtained.

For the blockmodeling, the Pajek program (http://mrvar.fdv.uni-lj.si/pajek/) was used.

Results

Project 5-100 was launched in 2013 to drive the increased publication activity of the Project 5-100 universities. Since joining the project, the number of publications co-authored with other organizations in the Project universities has grown significantly (Guskov 2018; Matveeva et al. 2019). We investigate the nature of these collaborations: domestic and foreign orientation, disciplinary specifics, and the co-authorship network's structure.

Dynamics of the number of affiliations of researchers

The process of preparing any publication is quite long. It may take more than 1 year from formulating the idea of a study to publishing the final paper. In Table 2, we observe that the Project universities significantly increase the number of published papers in just 3 years. This rapid growth in publication output has two explanations reasons. First, the Project universities had sufficient human and technological resources to support high publication activity, but were not sufficiently motivated to publish their results in a highly ranked journal, yet participation in Project 5-100 stimulated them. Second, after joining the project, the universities found researchers from other organizations to join forces in creating and preparing a study. Here we investigate the second issue, namely changes in the scientific collaboration of universities once the project was underway. Obviously, not all collaborations between universities reflected in bibliometric data are equal.

We start our analysis with that form of scientific collaboration whereby collaborations between organizations are provided by a single person. We thus counted the number of affiliated organizations in a publication with one author (solo publications). Solo publications are a very interesting case since the transfer of knowledge and technologies between universities entails one person. The organizational cost of these collaborations may be lower than when several researchers from different organizations communicate with each other. The transfer of knowledge between organizations via a single person is lower than through several people. Moreover, the stability over time of this collaboration is largely determined by the decision of a single person and this collaboration might be unfair (when a researcher simply adds their affiliation for a fee). A high share of solo publications with many affiliations within the general collaboration activity of universities may bring some risks, such as a low return on resources and their inefficient use.

Figure 1 shows how many affiliations, on average, one researcher has in the treatment and control groups of universities. In both groups, a single author typically has one affiliation. However, in the Project universities the number of solo publications with two affiliations is much higher than in the control group after 2014. The number of solo publications in which one author has three affiliations also increases in the Project universities. This growth of author affiliations may be affected by two mechanisms: the involvement of academics from other organizations at the Project universities and the participation of academics from Project universities in other scientific projects outside of these universities.

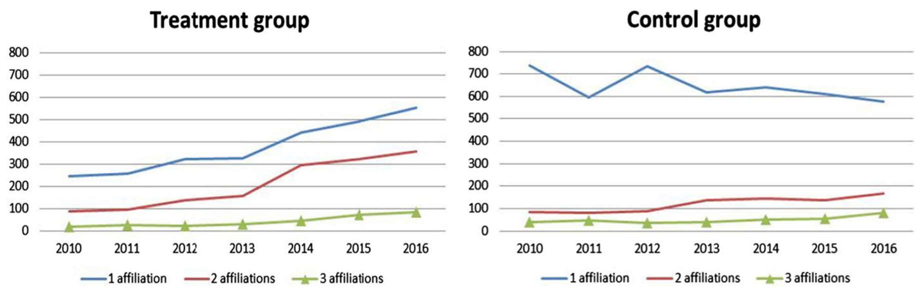

Fig. 1 Total number of publications with one author and 1–3 affiliations

Figure 1 also demonstrates stable growth in the total number of publications with one author from the Project universities after 2014, which might be caused by individual academic performance having been stimulated in these universities. In the control group, the number of solo publications after 2013 was on about the same level and dropped in 2016.

The number of solo publications with only Russian affiliations sees the same trend as the dynamics of all solo publications: the number of affiliations of a single author increased. Russian collaboration of both the Project universities and the control group only includes collaborations among the selected 30 universities. This means the dynamics of domestic collaboration in these groups are similar. Thus, most academics with several affiliations in the Project and control groups have a second affiliation with a Russian organization and much fewer academics are also affiliated with a foreign organization (Fig. 2).

Figure 2 presents how many solo publications in the two university groups have double and triple affiliations with foreign organizations. In the period 2012–2016, the number of solo publications with a foreign affiliation among the Project universities is four times larger. In the control group, the number of solo publications with a foreign affiliation grew in the last year.

These results show that after 2013 the Project universities enjoy significant growth in publications prepared in collaboration with other organizations. This reveals that participation in Project 5-100 stimulates universities to attract into their projects academics from other (also foreign) organizations or to send their own researchers to also work in other organizations.

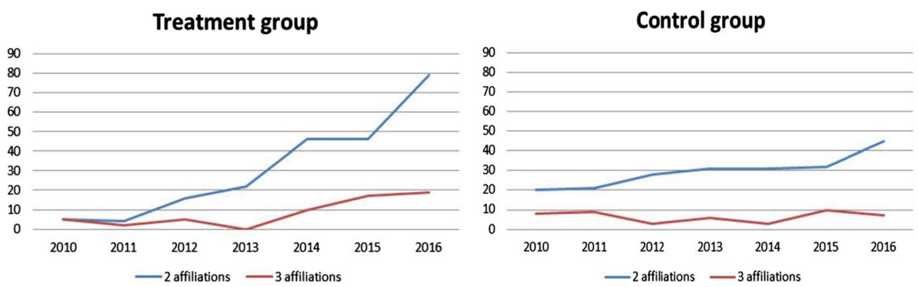

Fig. 2 Number of publications with one author and 2–3 affiliations at least one of which is a foreign affiliation

Dynamics of collaboration between organizations

We now look at the dynamics of collaboration by organizations with whom the two groups of universities prefer to collaborate. In this section, we consider all publications, not only solo publications. These collaborations cover two situations: when one person is working in several organizations or when many scholars from different organizations are working together on one project. To detect differences in international and domestic collaborations, we analyze university collaborations with Russian organizations, foreign organizations and the RAS separately. Joint publications with foreign organizations and the RAS, with foreign and other Russian organizations are not presented in Table 3. Before Project 5-100 started, both university groups had more joint publications with other Russian organizations than with foreign organizations and the RAS (Table 3). After 2013, in the Project universities the number of publications co-authored with foreign organizations is greater than with Russian organizations. A possible reason of this shift is that the Project universities concentrate not only on the number of publications but on their quality. International collaboration enhances the visibility and citations of publications (Ni and An 2018). The control group universities collaborate with Russian universities more often.

Patterns of collaboration also differ with respect to the quality of publications. In both groups, Q4 publications occur more often in collaboration with other Russian organizations. Still, it should be noted that the number of Q1 publications written by the Project universities and other Russian organizations doubled bwteen 2013 and 2016 (Fig. 3). International collaboration is prolific regarding Q1 output. The number of Q4 publications co-authored with foreign organizations is much lower in both university groups. In the Project universities, the number of Q1 publications written in co-authorship with foreign organizations rose during the whole period, with largest growth being observed after 2014. In the control group, Q1 output with foreign organizations dropped in 2016 (Fig. 4).

Collaboration of the Project universities with the RAS increases in both Q1 and Q4 segments after 2013. At the same time, Q4 output dominates within this collaboration. The growth of Q1 papers in the RAS might coincide with the start of government reforms in the RAS (http://www.ras.ru/news/shownews.aspx?id=030c7e45-bee3-429a-8d49-e0a79667e4f8) as collaboration rose between the Project universities and institutes of the RAS. The control group also has more joint publications with the RAS in the Q4 segment than in Q1 (Fig. 5).

Table 3 Dynamics of the number of publications written in collaboration with other organizations

	2010	2011	2012	2013	2014	2015	2016
With Russian organizations, without foreign ones and the RAS							
Treatment group	1157	1241	1440	1642	2020	2670	2770
Control group	2463	2367	2539	2459	2624	3172	3240
With only foreign organizations							
Treatment group	503	599	750	993	1642	2340	3022
Control group	1435	1437	1508	1591	1763	1976	2163
With only the RAS							
Treatment group	907	1122	1178	1593	2261	3222	3442
Control group	1009	1091	1181	1239	1446	1756	1958

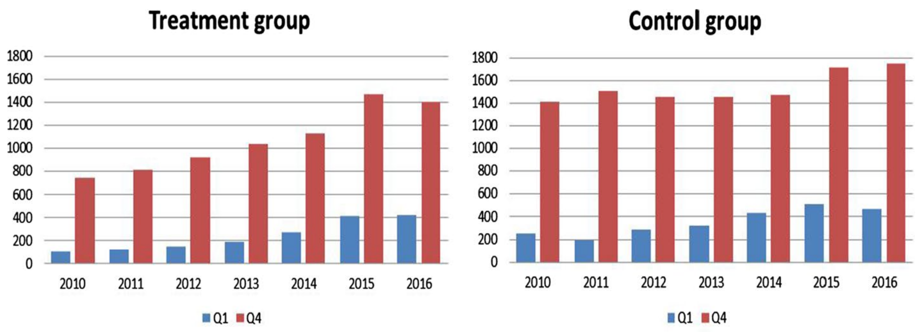

Fig. 3 Number of publications written in collaboration with Russian organizations (excluding the RAS)

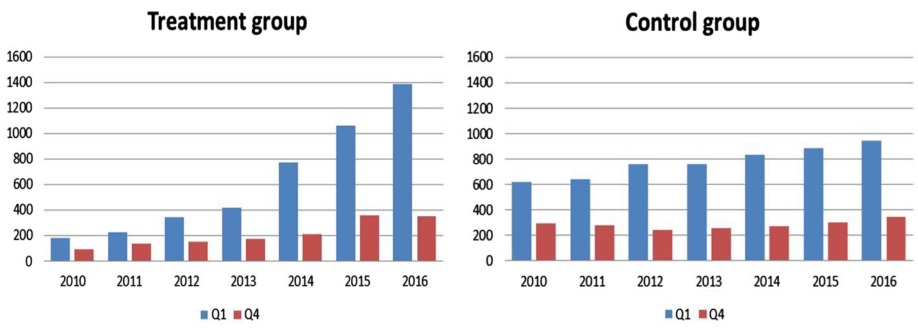

Fig. 4 Number of publications written in collaboration with foreign organizations (excluding the RAS)

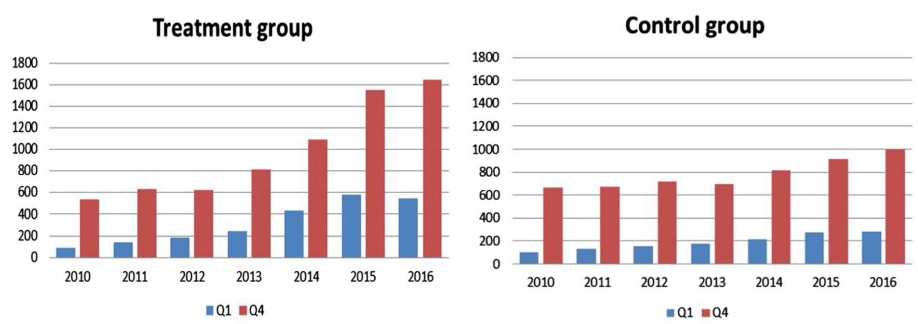

Fig. 5 Number of publications written in collaboration with RAS organizations (excluding foreign organizations)

We also analyzed how collaboration patterns differ by research area in the Project and control group universities. Figure 9 in the "Appendix" presents the number of publications written in co-authorship with other organizations by research area. After 2013, the Project universities intensified their collaboration with foreign organizations in all research fields. Before 2013, in Physics disciplines the Project universities collaborated more with Russian organizations and, once the project was underway, also with the RAS. The international collaborations of the Project universities become stronger than with Russian organizations in Life Sciences after 2013. In Social Science and Arts & Humanities, for the whole studied period the Project universities collaborate more often with other Russian organizations (excluding the RAS). The control group universities have more joint publications with Russian organizations (excluding the RAS) in all research areas. The control group collaborates with the RAS the least, even in Technical Sciences and Physics, which are traditionally developed by the RAS.

Thus, after joining the project, the Project universities intensified their collaboration with other organizations, with these collaborations being of various types. We observed that once the project is underway, the Project universities increase the number of publications where one researcher has double and triple affiliations. The collaboration trend of the Project universities shifted from mainly Russian universities to collaboration with foreign universities and the RAS. In Q1, both groups of universities collaborate with foreign organizations more often, but in Q4 more with Russian organizations. After 2013, in almost all scientific fields except Arts & Humanities Project universities began to collaborate more with the RAS and foreign institutions than with other Russian organizations. The control group universities have stable dynamics of the number of academic affiliations and these universities often collaborate with other Russian organizations.

Structure of the collaboration between universities

In the previous sections, we showed that the Project universities' research collaborations grew after Project 5-100 started and these collaborations varied by organization type, scientific field and publication quality. In this section, we analyze changes in the co-authorship network of the 30 Russian universities and their position in the network. First, we consider the collaborations outside of the selected 30 universities and between universities of the treatment and control groups. Then we analyze only the co-authorship of the Project and control group universities in the analyzed period.

The co-authorship network of the 30 Russian universities and all organizations in co-authorship with them consisted in 2010 of 1773 scientific organizations and 32,597 links (Table 4). The links reflect the co-authorship connections between organizations. Here only publications where at least one co-author comes from one of the 30 Russian universities are considered. The number of links is proportional to the number of co-authored

Table 4 Characteristics of co-authorship networks of the treatment group, control group, and co-authoring organizations in time

	2010	2011	2012	2013	2014	2015	2016
No. of 30 Russian universities and their co-authored organizations	1773	1884	2003	2248	2546	2781	2485
No. of links	32,597	60,398	137,695	118,337	180,822	276,196	314,546
Diameter	7	6	5	5	5	5	4
Mean distance	2.62	2.64	2.56	2.61	2.57	2.54	2.41
Link density	0.002	0.004	0.009	0.008	0.012	0.019	0.021
Average degree centrality of the 30 universities	19.29	21.48	54.58	66.52	154.45	279.9	329.74

organizations. For example, if one publication has affiliations with three organizations it provides three links between organizations (the first with the second, the first with the third, the second with the third). The number of links is therefore higher than the number of publications. Over the 6 years, this co-authorship network expanded significantly. Moreover, the number of links grew more than the number of organizations. This suggests that universities also collaborate with those who are already members of the network. In 2014–2016, the universities and scientific organizations in this network moved closer to each other: the diameter and average distance decreased. The average number of co-authored organizations for the 30 universities skyrocketed: from 19.29 in 2010 to 329.74 in 2016.

We observed that in 2016 the co-authorship network of the 30 Russian universities became denser than in previous years: the number of collaborating scientific organizations has grown, as has the connectivity of the organizations. Most Project universities significantly increased the number of co-authored organizations in the observed period.

Dynamics of collaboration between the two groups of universities

Thus far, we have analyzed the scientific collaboration of Russian universities with other organizations outside the two groups of studied universities. Now, we investigate how Project and control group universities collaborated with each other and the stability of this collaboration (co-authorship) during the analyzed period.

By using the (indirect) blockmodeling procedure we analyze changes in the co-authorship structure of the selected 30 Russian universities between 2010 and 2016. The obtained clustering results are presented by dendrograms for the first observed year (2010) and the last year (2016) (Fig. 6). The dendogram for 2010 clearly shows two clusters of the studied universities. A typical core–periphery structure can be observed in the matrix representation given in Fig. 7. There is the core cluster of four universities while the remaining universities are included in the periphery cluster. But a closer look at the periphery cluster

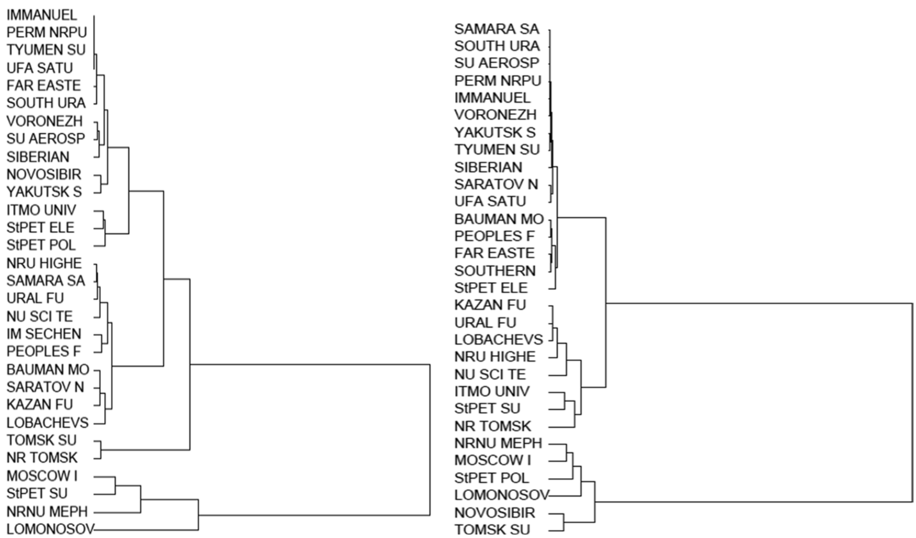

Fig. 6 Dendrograms for 2010 (left) and for 2016 (right)

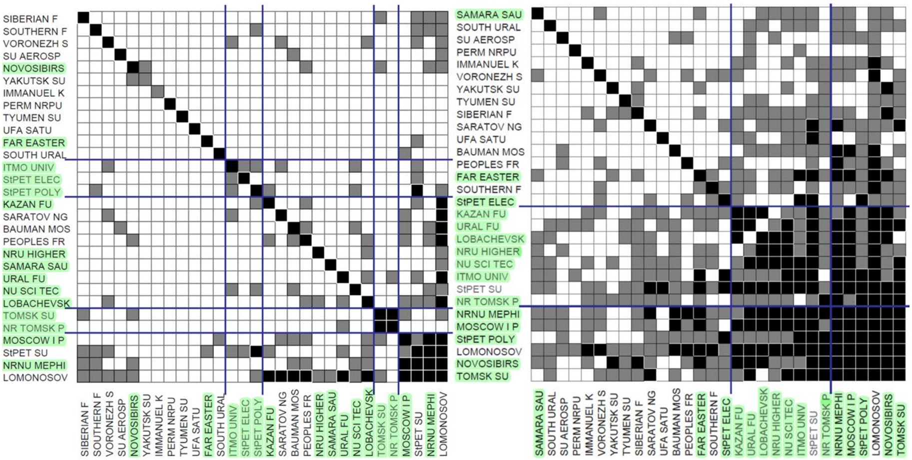

Fig. 7 Matrix representation of the blockmodel structure of 30 Russian universities in 2010 (left) and 2016 (right)

reveals an interesting structure consisting of four periphery subclusters. In 2016, the studied 30 universities can clearly be partitioned into 3 clusters.

Figure 7 presents the blockmodeling results represented by matrices for the 30 Russian universities in 2010 and 2016. The cell color indicates the number of joint publications between universities: black—more than 5 papers, grey—from 1 to 4, white—zero papers. The Project universities are highlighted in green. The clusters thus obtained are separated by blue lines.

In addition, in the period 2010–2014 a core–periphery blockmodel structure is visible (see Fig. 10 in the "Appendix") in which universities from the core group are strongly connected to each other and with the periphery, while universities from the periphery are not connected to each other (Cugmas et al. 2020). In the second period, 2015–2016, the universities are more connected to each other. Before 2013, the core of strongly linked universities was small and split. After 2014, the core increases and the number of non-links is reduced significantly. Once Project 5-100 was underway, the control group universities also increased the number of joint publications with each other.

The observed results also reveal that before 2013 the core group of universities mostly comprised two large universities from the control group and only a few Project universities. In 2016, the core cluster consisted of five Project universities and Moscow State University. Thus, participation in the project stimulated the universities to intensify their collaboration with each other.

Figure 7 presents the composition of the clusters in the first and last years. In 2010, universities in each cluster are often located in the same region. The core cluster consists of two large Russian universities not included in Project 5-100 and two physical universities with a high level of collaboration on mega-science projects, namely: Moscow State University, *National Research Nuclear University*, St. Petersburg State

University, and *Moscow Institute of Physics and Technology*. Those appearing in italics are included in Project 5-100. In 2016, only one university from the control group is still in the core and the rest are Project universities. These are: *National Research Tomsk State University, Novosibirsk State University,* Moscow State University, *St. Petersburg State Polytechnical University, Moscow Institute of Physics and Technology, and National Research Nuclear University*. In the last observed year, 2016, the core universities with a large number of joint papers written by researchers between the core universities are geographically spread. This is a significant difference between the core in the first and the core in the last observed year.

Figure 8 presents the blockmodels obtained for the first year, 2010, and the last year, 2016. As mentioned, in 2010 (see the blockmodel to the left of Fig. 8) there is a core cluster of universities that strongly collaborate with each other and there are four periphery clusters. The latter ones have the following structure: the first periphery cluster (P1) consisting of two universities in Tomsk which strongly collaborate with each other and have no collaboration ties with the other universities; universities of the second periphery cluster (P2) do not collaborate with each other but slightly collaborate with the core cluster; universities of the third periphery cluster (P3) weakly collaborate with each other and do not write joint papers with the other universities; while the last periphery cluster (P4) is isolated.

The blockmodel for the last observed year, 2016, has a clear and simple structure (see the blockmodel to the right of Fig. 8). There is a strongly connected core cluster (C), a weaker core cluster (CW) which is less strongly connected within the cluster but strongly connected with the core cluster, and a periphery cluster (P) with no collaboration ties inside the cluster, but less strong ties with the core cluster and weak ties with the weaker core cluster. Here, of the two large Russian universities found in the core cluster in 2010 one moved to the weaker core cluster and joined some other Project universities. Thus, cluster CW consists of the Project universities and St. Petersburg

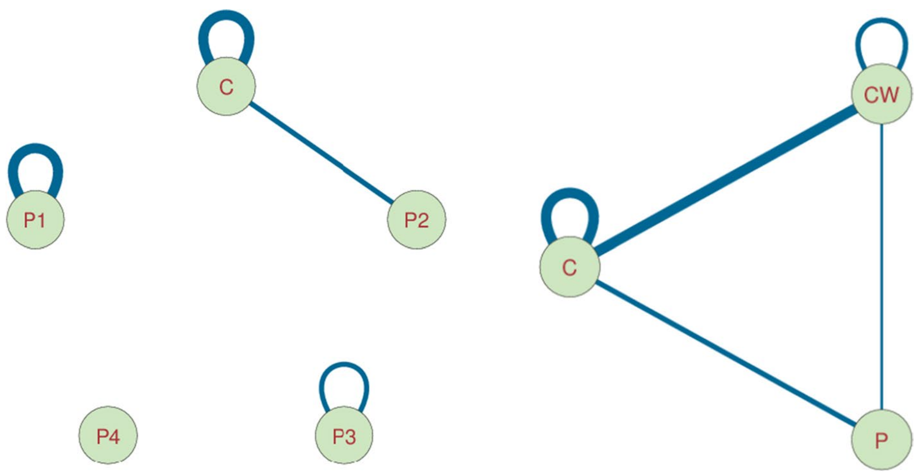

Fig. 8 Schematic visualization of blockmodels for 2010 (left) and 2016 (right). *C* core cluster, *CW* weaker core cluster, *P* periphery clusters

State University. The periphery cluster includes mostly universities not participating in Project 5-100 (see Table 6 in the "Appendix").

Conclusions

The results of this research indicate that the Russian government excellence initiative Project 5-100 has led to changes in the collaboration patterns of the Project universities. In previous studies (Turko et al. 2016; Matveeva et al. 2019), a positive effect of Project 5-100 on university publication output was found. Here, we reveal that the project has also altered the structure of the collaboration of the Project 5-100 universities. The Project universities intensified both their foreign and domestic collaboration, although these collaborations differ by publication type and rates of growth.

We analyzed affiliations and the co-authorship network analysis to investigate the collaboration patterns inside and outside the two university groups (the Project and control group universities). We established that after 2014 there is a significant difference in the collaboration patterns of the Project universities, but not in the non-participants of the project.

After 2014, the Project universities had a higher number of affiliations in solo publications, thereby intensifying the type of research where one researcher works on projects in different organizations. This is typical of both national and international collaboration. Before 2013, the Project universities had joint publications more often with other Russian organizations. After 2014, they collaborate more often with foreign institutions and the RAS. The control group of universities collaborates with other Russian organizations (excluding the RAS) throughout the whole period.

We also observed disciplinary and quality differences. Both university groups have more Q1 publications when collaborating with international partners. Q4 output is typical of collaboration with Russian organizations (excluding the RAS). After 2013, in Natural Sciences the Project universities collaborate more with the RAS and foreign institutions than with other Russian organizations.

The co-authorship network of the 30 Russian universities became larger and denser over time. The position of the Project universities in this network improved; they became more integrated into the academic network. Yet, the structure of collaboration within this group is not stable. In recent years, the Project universities have formed a core cluster with strong co-authorship links with other universities.

We revealed that Project 5-100 stimulates universities to intensify their scientific collaboration. On one hand, the newly formed collaboration patterns are oriented to international cooperation and this has increased the integration of Russian science into the world academic community. Moreover, the Project universities form a large core cluster inside the Russian academic community. On the other hand, this is not the case for the non-participating Russian universities. Moreover, the Project universities have intensified the specific collaboration type where researchers work in several organizations. A question arises about the stability of such intense scientific collaboration when Project 5-100 finishes given that scientific collaboration requires considerable funding.

We analyze collaboration patterns based on sufficiently high-quality publications as included in the first indices of the WoS Core Collection (SSCI and SCIE). We concentrate on this data since publications from these indices enjoy high visibility in world-class science and the Project universities wish to be a part of it. Of course, other scientific collaborations types could be observed, e.g. by including national and foreign journals without quartiles. This study is also limited by the time period analyzed. Some universities from the control group were included in the second wave of Project 5-100 after 2016 and thus we were unable to analyze the treatment and control group universities after that year. In addition, using an extended observation period, future work could seek to analyze the international collaboration patterns of Project universities with top world universities.

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Appendix

See Figs. 9, 10 and Tables 5 and 6.

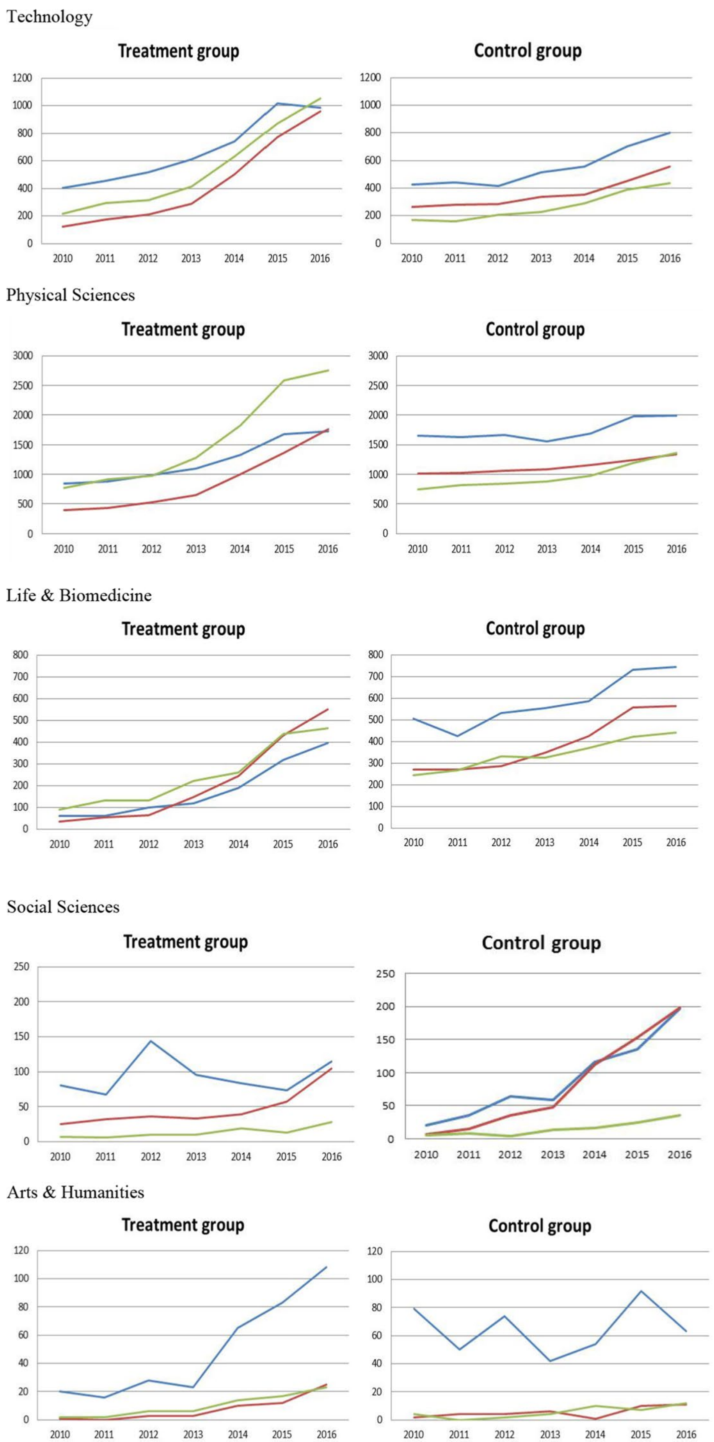

Fig. 9 Total number of publications written in co-authorship by research area—with Russian organizations—with foreign organizations—with the RAS

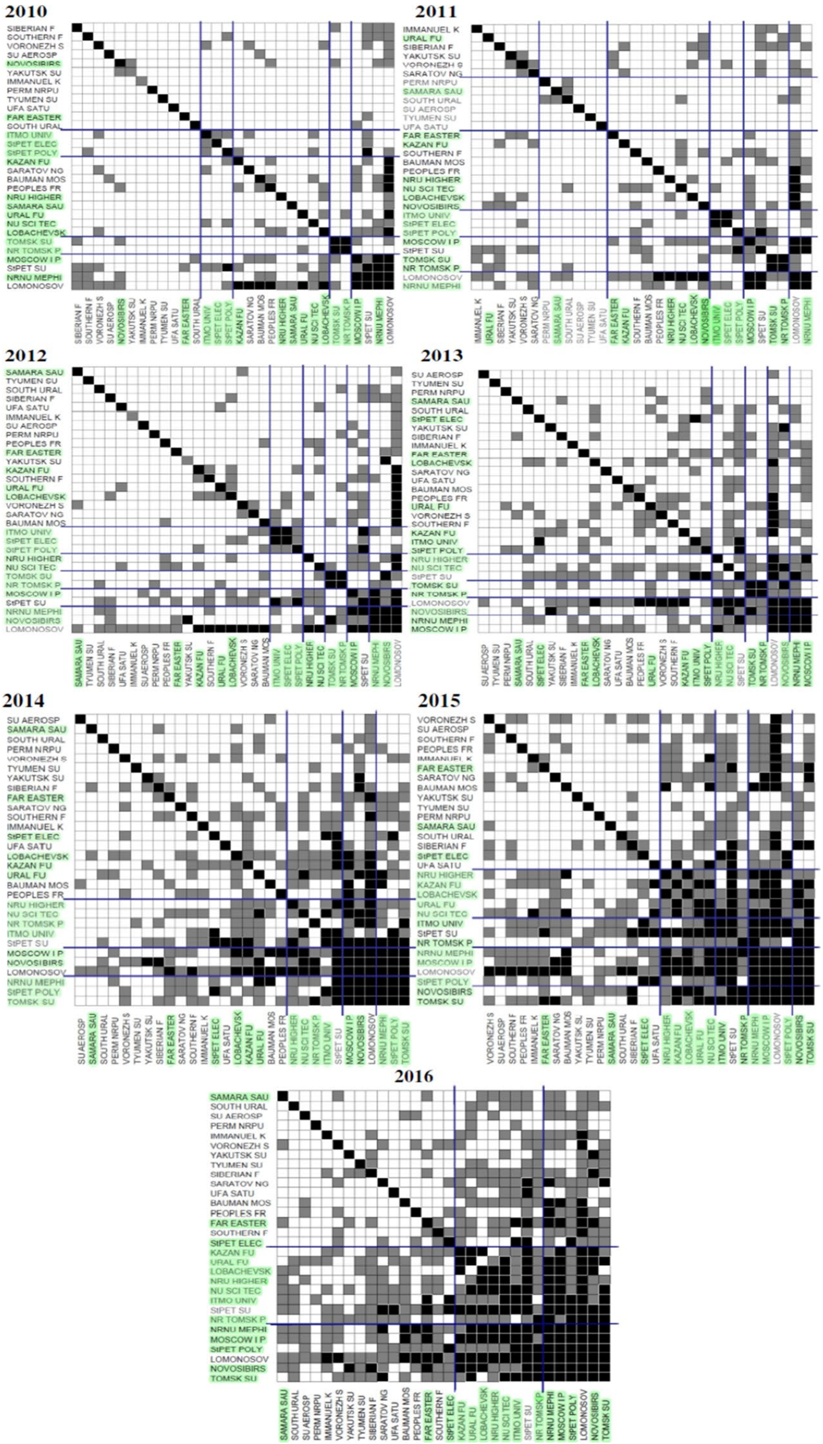

Fig. 10 Blockmodel structure of the 30 Russian universities between 2010 and 2016

Table 5 Comparative indicators of the treatment and control group universities

	2010	2011	2012	2013	2014	2015	2016
Share of publications in Q1							
Treatment group	17.20	20.38	25.58	27.42	32.78	31.02	32.17
Control group	12.33	14.14	17.89	18.07	20.49	20.03	19.32
Share of publications in Q4							
Treatment group	51.73	49.87	46.78	42.25	36.10	32.99	31.85
Control group	57.77	60.40	51.52	52.54	47.56	45.68	44.45
Share of publications cited one or more times							
Treatment group	77.31	79.73	80.76	80.62	79.98	76.01	60.72
Control group	73.71	73.16	75.10	74.72	74.33	65.96	47.59

Table 6 Composition of the clusters from core to periphery in 2010 and 2016

Cluster	2010	2016
1	Moscow State University ***C***	**National Research Tomsk State University *CW***
	National Research Nuclear University	**Novosibirsk State University**
	St. Petersburg State University	Moscow State University
	Moscow Institute of Physics and Technology	**St. Petersburg State Polytechnical University**
		Moscow Institute of Physics and Technology
		National Research Nuclear University
2	***P1***	**NR Tomsk Polytechnic University**
	NR Tomsk Polytechnic University	St. Petersburg State University ***C***
	National Research Tomsk State University	**St. Petersburg State University of Information Tech**
		National University of Science & Technology
		NR University Higher School of Economics
		Lobachevsky State University of Nizhny Novgorod
		Ural Federal University
		Kazan Federal University
3	***P2***	**St. Petersburg State Electrotechnical University *P***
	Lobachevsky State University of Nizhny Novgorod	Southern Federal University
	National University of Science & Technology	**Far Eastern Federal University**
	Ural Federal University	Peoples' Friendship University of Russia
	Samara National Research University	Bauman Moscow State Technical University
	NR University Higher School of Economics	Ufa State Aviation Technical University
	Peoples' Friendship University of Russia	Saratov State University
	Bauman Moscow State Technical University	Siberian Federal University
	Saratov State University	Tyumen State University
	Kazan Federal University	North-Eastern Federal University in Yakutsk
		Voronezh State University
		Baltic Federal University
		Perm National Research Polytechnic University
		Moscow Aviation Institute
		South Ural State University
		Samara National Research University

Table 6 (continued)

Cluster	2010	2016
4	***P3*** **St. Petersburg State Polytechnical University** **St. Petersburg State Electrotechnical University** **St. Petersburg State University of Information Technologies**	
5	South Ural State University ***P4*** **Far Eastern Federal University** Ufa State Aviation Technical University Tyumen State University Perm National Research Polytechnic University Baltic Federal University North-Eastern Federal University in Yakutsk **Novosibirsk State University** Moscow Aviation Institute Voronezh State University Southern Federal University Siberian Federal University	

Participants are highlighted in bold

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