Measuring Excellence in Russia: Highly Cited Papers, Leading Institutions, Patterns of National and International Collaboration

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Abstract

In this study, we discover Russian "centers of excellence" and explore patterns of their collaboration with each other and with foreign partners. Highly cited papers serve as a proxy for "excellence" and coauthored papers as a measure of collaborative efforts. We find that currently research institutes (of the Russian Academy of Sciences as well as others) remain the key players despite recent government initiatives to stimulate university science. The contribution of the commercial sector to high-impact research is negligible. More than 90% of Russian highly cited papers involve international collaboration, and Russian institutions often do not play a dominant role. Partnership with U.S., German, U.K., and French scientists increases markedly the probability of a Russian paper becoming highly cited. Patterns of national ("intranational") collaboration in world-class research differ significantly across different types of organizations; the strongest ties are between three nuclear/particle physics centers. Finally, we draw a coauthorship map to visualize collaboration between Russian centers of excellence.

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Introduction

Scientometricians choose an excellence-based approach to measuring science when they want to move from the question "whose *average* is better?" to "whose *best* is better?". Comparison of the peak scientific achievements may be more telling than tails analysis involved in the calculation of averages.

According to Zitt, Ramanana-Rahary, and Bassecoulard (2005, p. 388), "highly-cited articles are among the most commonly used indicators" for measuring "excellence". Tijssen, Visser, and van Leeuwen (2002, p. 381) evaluate the potential of highly cited papers for identifying "centers of scientific excellence". They constantly underline the complex nature of "excellence", but still conclude that methods based on highly cited papers "offer important added value" (p. 395) and are preferable to calculation of the averages. In another example, King (2004) chooses this approach to rank 31 countries in his evaluation of the scientific impact of nations, preferring it to raw publication or citation counts. However, he remarks that rank order would not be seriously affected if the plain citation indicator had been used, which is in line with findings of Aksnes and Sivertsen (2004), who showed that a significant share of the national citation impact may be due to the effect of a few highly cited papers.

Recently, indicators based on highly cited papers emerged in a new role, important for science and higher education policy. They have become a component of almost all global university and institutions rankings, either directly, as in a new Leiden Ranking (Waltman et al., 2012) or Webometrics Ranking introducing new "excellence" indicator (CCHS-CSIC, 2012), or indirectly through a number of highly cited authors, as in ARWU (Liu & Cheng, 2005), or a number of papers published in the "most influential scholarly journals", as in Scimago Institutions Rankings (Scimago Research Group, 2010).

The term *highly cited paper* may be defined in a number of ways. We follow the approach of the Essential Science Indicators database produced by Thomson Reuters, where highly cited papers are the most cited 1% by field and year of publication. Other definitions are found in the literature; for example, Narin, Frame, and Carpenter (1983), whose results we use as a reference point, choose a threshold of 1.3%. Schilling and Green (2011) take the data from another

Thomson database and, consequently, limit their study by a fixed number of the most cited papers in different disciplines. Similar approaches also exist in patent bibliometrics; for example, Nemet and Johnson (2012) analyze patents in the top 25th percentile of citations received.

The objective of this study was to examine Russian science from the perspective of highly cited papers. To identify national centers of excellence is an interesting problem in itself. In the case of Russia, a highly cited papers approach is particularly appropriate, as it gives even more correct and interpretable results than analysis of the entire national output. In Russia, conclusions of a bibliometric investigation of national science are often declared to be inadequate on the basis of insufficient availability of Russian journals in international scientometric databases.[1] Indeed, this factor may play a role when we count total number of papers and/or citations. However, an analysis in terms of highly cited papers is almost completely free from this bias. The overwhelming majority of highly cited papers are published in international journals, or at least in national journals with high visibility. The latter are already included in the Web of Science. Thus, the addition of peripheral Russian journals to databases will not increase the number of highly cited Russian papers. Indicators based on high-impact articles are, one might say, almost coverage-independent for large international scientometric indexes.

Highly cited Russian papers have received little attention in the literature. Only the classic work by Narin et al. (1983) explored Soviet high-impact research in detail. They arrived at the conclusion that Soviet science is "isolated" and its level of citedness is dramatically low. An additional value of this survey for us is that its authors acknowledged the same problem of finding "centers of excellence" in the Soviet Union. We compare the results of our study with those obtained by Narin et al. (1983) in the final section of the present paper. In another more recent work (Markusova, Ivanov, & Varshavskii, 2009) highly cited papers were discussed in the context of a study of the Russian Academy of Sciences output.

The structure of this paper is as follows: First, we investigate the general characteristics of highly cited Russian papers, their total number, and disciplinary structure. Next, we explore the role of international collaboration in the process of creating a highly cited paper coauthored by Russian scientists. This interest is motivated by the following two factors:

[1] Although there were reasonable arguments that Russian journals are, on the contrary, overrepresented in Thomson databases (e.g. Zitt, Ramanana-Rahary, & Bassecoulard, 2003).

- Highly cited papers often involve extensive international collaboration (Aksnes, 2003);
- International coauthorship typically increases visibility of Russian papers and proves to be "profitable" in terms of citations (Pislyakov, 2010).

Thus, our hypothesis is that the combination of these factors causes international collaboration to play a key role in determining highly cited Russian papers. If this is confirmed, it is essential to investigate the relative share that Russian institutions have in the process of international collaboration that results in publishing a highly cited paper. To what extent can we say that Russian authors dominate or are dominated in such a collaborative work? In addition, we identify key partner countries and explore their influence on the probability of a Russian paper becoming highly cited.

Furthemore, we focus on Russian "centers of excellence" prolific in producing highly cited papers. They are considered by type of institution: research institutes of the Russian Academy of Sciences / Russian Academy of Medical Sciences (RAS/RAMS), non-RAS institutes, and the higher education sector. Due to the unavailability of comparable data on staff of the institutions and their total output (the latter being a consequence of the absence of the standard English names and the presence of a great diversity of variants), we use absolute numbers of highly cited papers. So, in this paper the term *center of excellence* is used in the sense of, for example, Narin et al. (1983) and reflects the *total* high-impact output of the institution.[2] This differs from the size-normalized approach of Tijssen et al. (2002) and van Leeuwen et al. (2003). Other approaches to defining *centers of excellence* also exist, for example, the "bottom-up" methodology of Abramo, D'Angelo, and Di Costa (2009) starting from individual authors and their publication practices.

Our last research question is how these leading institutions interact with each other. Are there any patterns of intranational collaboration between Russian institutions which frequently result in highly cited papers? We approach this issue from two perspectives, first on the level of cooperation between different types of institutions and then on the level of coauthorship between individual organizations. Finally, we draw a map to visualize the latter type of collaboration.

[2] Most probably the same reasoning led Terekhov (2012) to take the same approach. This most recent paper on analysis of Russian nanoscience publications also uses the term *center of excellence* without size normalization.

Methods

The web interface of Thomson Reuters's *Essential Science Indicators (ESI)* database was used to identify highly cited papers. This product contains publication counts and citation data for countries, organizations, journals, and scientists. It indexes more than 10,000 journals in the areas of science, technology, medicine, and social sciences. It does not include arts and humanities journals. Only two document types are indexed by *ESI*, namely, scientific articles and reviews. All letters to the editor, errata, biographical items, and so on are omitted.

All journals in *ESI* are categorized into one of 21 broad fields of research, with no journal being assigned to more than one field. Multidisciplinary journals (such as *Science*, *Nature* or *Proceedings of the National Academy of Sciences [PNAS]*) form the 22nd category. Each paper inherits its field category from the journal where it is published. Papers from multidisciplinary journals form an exception. They are reclassified into specific fields by an automated procedure that takes into account field representation of the journals citing these papers and journals cited by them. If this method does not produce a reliable result, the paper remains in a multidisciplinary category.

A special section of *ESI* lists highly cited papers. By definition, "highly cited paper" in *ESI* is a paper that ranks among top 1% most cited articles. Because citation rates vary significantly by scientific field (e.g. Glänzel & Moed, 2002) and recent papers have had less time to be cited than older papers, *ESI* adjusts for this. For each year of publication and for each field citation thresholds are calculated. Those papers that reach these thresholds fall into the top 1% most cited among all articles published in a given year/field and are defined as "highly cited". As the thresholds are integer numbers, the actual share of highly cited papers may be slightly greater (1.02% in our sample). The thresholds may differ significantly from field to field; for example, at the time of our investigation, a paper in neuroscience published in 2000 should have received 273 citations to be listed as highly cited, whereas a similar paper in mathematics had a threshold of only 60 citations.

Our data were collected in March 2011 when *ESI* contained papers that had been added into the database[3] from 2000 to 2010. Only documents published in 2000–2009 were included into our study. The most recent highly cited papers were omitted to avoid edge effects, as citation thresholds for 2010 papers were too low and a paper could become highly cited due to temporary circumstances. Another important remark on *ESI* data should be made. In the course of our study we found a decrease in the total number of highly cited papers published in 2008–2009 (and 2010, although they are not considered in this paper). As, by definition, one out of every 100 papers published in a given year becomes highly cited, and there is a constant 3% to 5% increase in world publication output, this finding indicated some inconsistency within the database. We have reported the issue to Thomson Reuters and, as a result of their investigation, a notice has been published (Thomson Reuters, 2011) that acknowledged an omission of 400,000 recent papers from the *ESI*.[4] However, we expect that this data incompleteness did not significantly affect our results, because of the following:

- about 4,000 omitted highly cited papers constitute less than 5% of their total set;
- as it followed from communication with Thomson Reuters, omission of papers was not related to their authors' affiliation, so the international comparisons most probably remain reliable.

Although the detected inaccuracy has not led to recollecting, reverification and reanalyzing the entire data set, it has, of course, considerably limited the scope of our analysis across time. Therefore, we examined highly cited papers published in 2000–2009 as a whole set and did not attempt to analyze the internal structure for each year.

Papers were attributed to countries according to their authors' affiliations. For example, if at least one co-author had a Russian institutional affiliation, then it was considered a "Russian paper". Given international coauthorship the same paper may also be "Russian", "French", "German", and so on. This is the so-called "whole counting" method. Still, when the relative role of a country or institution in highly cited paper's authorship was analyzed, another method was implemented, "institutional fractional counting". If a paper had *N* different institutional

[3] There is a slight difference in *ESI* between "year of publication" of a paper and its "database year", a year when it was added to the database. They may be different for documents that appeared in the last 2 months of a year, but this effect does not play a significant role in our study.
[4] As a part of the database update in January 2012, all documents previously omitted were added.

affiliations, each institution was assumed to have a contribution of 1/*N*. This did not apply to subdivisions (departments, laboratories): They were all considered as one institution. A more thorough method of "author fractional counting", when institutions' contributions are divided in proportion to the number of authors from each organization, could not be applied because there was no association between each author and each affiliation in *ESI*. The same institutional approach, as well as combining of whole and fractional counting for different purposes, is applied by NSF in its reports (National Science Board, 2012, pp. 5–33).

ESI tries to standardize institutional names and make them appear identical in the database even if different authors used different English versions of the same organization's name. Unfortunately, this problem is often not resolved satisfactorily for institutions from non-English-speaking countries. Abramo, D'Angelo, & Caprasecca (2009, p. 207) call it "the most obstinate obstacle confronting the bibliometrician" and use special disambiguation algorithm for Italian science. We had to perform this process manually for all 900+ Russian highly cited papers. Thus, all Russian papers were attributed to institutions with 100% certainty.[5] The final processed data was input into the Microsoft Access database.

Visualization of the institutional coauthorship was performed with the Pajek program. This freeware product visualizes social networks and makes it possible to create "energized" graphs (de Nooy, Mrvar, & Batagelj, 2005, p. 16). We consider institutions as nodes and the number of collaborative papers as the strength of ties between them. After energizing, the distance between nodes indicates the activity of the collaboration between corresponding organizations. The closer the nodes are to each other, the more highly cited papers were published in collaboration. The Fruchterman-Reingold (Fruchterman & Reingold, 1991) energizing algorithm was implemented. Sometimes an author may have several affiliations in the same paper. In this case, we also consider the paper as collaborative, although a spot check showed that this pattern of "collaboration" is atypical for Russian publications.

[5] An additional obstacle with Russian research organizations is that the institutes of the Russian Academy of Sciences (RAS) are all united in *ESI* into one organization, RAS. Moreover, for some papers ESI misses this attribution, so indicators for RAS as a whole are also incorrect in the database. This is a well-known problem (cf. Markusova et al., 2009).

Results and discussion

There are 927 highly cited papers (co-)authored by Russian scientists and published in 2000–2009. They constitute 1.0% of the total amount of highly cited articles listed for these years. According to *ESI*, the share of all Russian papers in the total world output in 2000–2009 is about 2.8%. Thus, the Russian contribution to the corpus of highly authoritative scientific literature is almost 3 times lower than its share in all *ESI*-indexed papers. Only 1 of 272 Russian papers becomes highly cited. Miyairi and Chang (2012) remark that Russia ranks 30th among all the countries by number of highly cited papers. At the same time, we found that it is 11th if we look at the total output.

Further in this section we focus on the disciplinary structure of Russian highly cited papers, explore international coauthorship in high-impact research, find the Russian institutions most prolific in creating leading articles, and study the collaboration between them.

Disciplinary structure

Table 1 shows the distribution of Russian highly cited papers across scientific fields. The most striking characteristic of this distribution is a strong domination of physics, which accounts for half of all papers. Six times fewer papers are attributed to each of the next two fields, engineering and clinical medicine. More than 50 highly cited articles were published in each of the other two fields, chemistry and geosciences. At the other end of the scale, during 10 years only one Russian paper became highly cited in economics/business and in immunology. A similarly poor performance can be observed in computer science, pharmacology, agriculture, neuroscience, and psychiatry.

The small number of highly cited papers in some of the categories may be the result of the modest total output of Russia in those categories. To correct for this, the shares of Russian papers that have become highly cited were calculated in Table 1 for each scientific field. This indicator is similar to the HCP index of Tijssen et al. (2002). The leader remains unchanged, physics, with 0.68% of all papers in this category becoming highly cited. Note that even the most advanced Russian discipline lags behind the world in terms of share of highly cited papers in total scientific output. Medicine, with 0.61% becomes the closest rival, followed by biology/biochemistry (0.43%), engineering (0.40%) and space science (0.32%; to exclude outliers, we limit ourselves to categories with more than 20 papers). Although the Russian mathematical school is traditionally considered strong (e.g. Karp & Vogeli, 2010), we observed a poor performance of mathematicians in terms of absolute number of highly cited papers, as well as in terms of their share in national output (0.22%). Although mathematics may be considered as "especially vulnerable to the abuse of citation statistics" (Adler, Ewing, & Taylor, 2009, p. 3), we have another unexpected example in the case of chemistry, where the proportion of Russian papers becoming highly cited (0.11%) is one of the lowest among scientific fields. This is surprising given that chemistry occupies the second place by number of papers as well as citations in total Russian output and the fourth place by number of highly cited papers.

TABLE 1. Distribution of Russian highly cited papers across scientific fields.

Field	Papers	% of total Russian output
Physics	468	0.68
Engineering	78	0.40
Clinical Medicine	74	0.61
Chemistry	62	0.11
Geosciences	57	0.31
Biology & Biochemistry	43	0.43
Materials Science	29	0.19
Space Science	27	0.32
Mathematics	26	0.22
Molecular Biology & Genetics	13	0.23
Environment/Ecology	12	0.44
Plant & Animal Science	9	0.15
Microbiology	6	0.19
Social Sciences	6	0.23
Agricultural Sciences	3	0.16
Neuroscience & Behavior	3	0.15
Psychiatry/Psychology	3	0.25
Computer Science	2	0.07
Multidisciplinary	2	0.20
Pharmacology & Toxicology	2	0.38
Economics & Business	1	0.32
Immunology	1	0.24
Total	**927**	**0.37**

International collaboration

It was mentioned previously that international collaboration is often a prerequisite for high-impact research. For example, Fu, Chuang,Wang, and Ho (2011) find that 47% of Chinese highly cited papers are internationally collaborative; the percentage is 2 times higher than that for the total output of China. Intuitively, this effect would be more pronounced for scientifically peripheral countries, and Aksnes (2003) finds that 63% of Norwegian highly cited papers have coauthors from other countries (he analyzes an earlier period, 1981–1996). In the case of Russia we get an astonishing result: only 75 out of 927 papers that we analyzed were written by Russian scientists only. About 92% of Russian highly cited papers involved international collaboration, which is several times higher than this share in the overall Russian output (35%). In some disciplines, the share of internationally coauthored papers reaches 100%. All 57 Russian papers that have become highly cited in geosciences, 27 in space science, 13 in molecular biology, and 12 in ecology have foreign coauthors, speaking of the categories with more than 10 highly cited articles.

This observation motivates us to study internationally coauthored highly cited Russian papers in more detail to gain a better understanding of the relative role of Russian authors there.

Share of Russian institutions. Most often, highly cited Russian papers have coauthor(s) from one foreign institution (23%). We also found a paper that had 188 institutional coauthors from abroad. If we consider only papers that involved international coauthorship, the average number of international collaborators will be 12.2, the median 3.

If we apply institutional fractional counting to highly cited Russian papers, their numbers are reduced from 927 to 312. The average share of Russian authors in highly cited papers (in the sense of our institutional approach) is about one third (34%) and approximately coincides with its median (33%).

It is more illuminating, however, to look at the characteristics of collaborative papers only. Figure 1 separates purely Russian papers and shows the distribution of all other articles by quintiles of proportion of Russian institutions in the list of their authors' affiliations. It is clear that Russia is generally dominated by other countries in collaborative highly cited papers. Most often, Russian institutions account for less than 20% of authors' addresses (37% of papers are in the first quintile). For collaborative papers the average share of Russian institutions is 28%, the median is 25%.

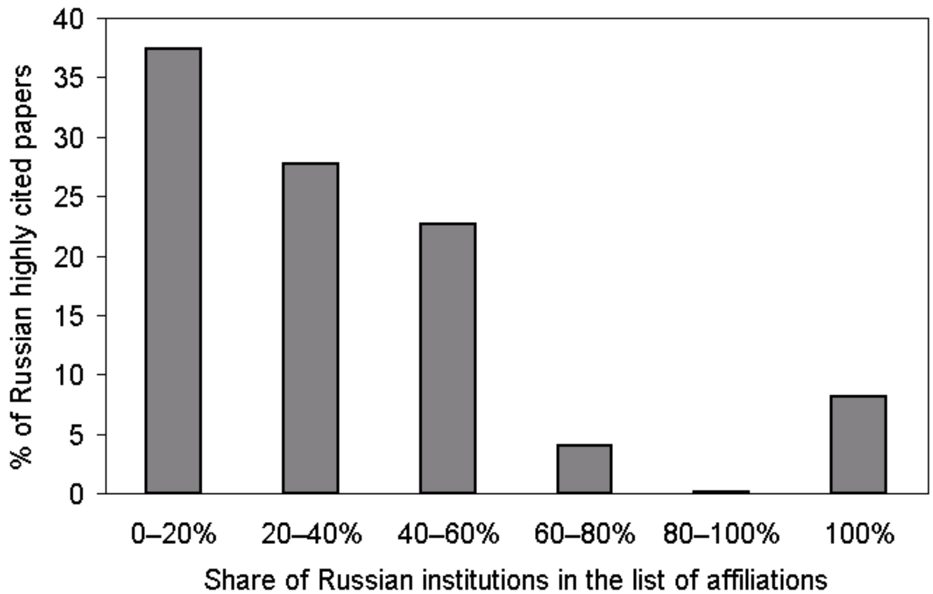

FIG. 1. Percentage of Russian highly cited papers with a corresponding share of Russian organizations in total number of institutional affiliations, by quintiles. The share of articles written exclusively by Russian authors is shown separately (100%).

The share of Russian institutions' participation in highly cited papers differs significantly across disciplines. If we limit ourselves to fields of science with more than 20 highly cited Russian papers (in terms of whole counting, all papers and not only collaborative ones are considered), the highest average share of Russian organizations is in chemistry and mathematics (54%) and the lowest in clinical medicine (15%).[6] Physics, the most productive discipline, demonstrates a moderate 32% share despite the fact that some physics papers are written in large collaborations comprising several dozens of affiliations. Transition to fractional counting also affects rankings of Table 1. The greatest changes are observed for mathematics (three positions up) and clinical medicine (five positions down).

[6] There is no unanimous evidence in the literature whether these levels of internationalization are inherent to the disciplines themselves. More often, papers in mathematics were found to have fewer coauthors (Abramo, D'Angelo, & Murgia, 2013; Newman, 2004), although in Adams, Black, Clemmons, and Stephan (2005) mathematics occupies the third place among 11 disciplines by the mean share of foreign affiliations. Also, Abramo et al. (2013) find medicine to be the most collaborative discipline, but at the same time chemistry is second.

On one hand, this shows a significant contribution of Russian authors to highly cited papers in chemistry and mathematics and their rather subsidiary role in medicine. On the other hand, this may be interpreted as a lack of internationalization of the former disciplines. It should be noted that the second argumentation wins in terms of percentage of highly cited papers in the total national output. As mentioned earlier, 0.61% of Russian papers in medicine have become highly cited, whereas for chemistry and mathematics the share is only 0.11% and 0.22%, respectively.

Top collaborating countries. If we explore international coauthorship at the level of whole countries, we see that 33% of highly cited Russian papers resulted from bilateral collaboration, 19% have author affiliations from three countries, and 7% from four countries. The maximum is a paper with authors from 40 countries.

Table 2 shows the most active partners of Russia in highly cited output. It allows us to compare the share of each country's coauthorship in high-impact research with that in the overall set of Russian publications. In general, the relative positions of partner countries remain the same; more close partnership results in a greater number of highly cited papers. One may notice the relative growth of the U.K. and, especially, U.S. roles in the highly cited column of Table 2. More than a half of all Russian highly cited papers are published with coauthors from the United States. Interestingly, the share of the United States in all high-impact articles is almost the same as in highly cited papers with Russian coauthors. In a sense, this means that the United States does not "notice" collaboration with Russia; their works may be found in the subset of highly cited Russian papers as frequently as in the whole high-impact output.[7] Another country whose share has increased significantly in the set of coauthored highly cited papers when compared with "ordinary" papers is China: It ranked only 13th with overall collaboration with Russia. However, this is explained by multinational papers rather than by unique characteristics of Russia-China coauthorship, as there is only one bilateral paper with China and no trilateral papers, and all others involve more than three partner countries.

[7] To more exactly assess the relative importance of a country as a partner against a world baseline one could use "co-authorship affinity index" introduced previously (Glänzel, 2000; Glänzel & Schubert, 2001). But in our case the share of high-impact Russian papers is small and the share of collaborative papers among them is large. As a result, affinity indices closely follow the numbers in the "Share in Russian output" and "Share in world output" columns for highly cited papers of Table 2.

TABLE 2. Russia's key collaborators: coauthorship shares, total shares, and Jaccard index for collaboration with Russia (%).

Country	Highly cited papers			All papers		
	Share in Russian output	Share in world output	Jaccard for collaboration with Russia	Share in Russian output	Share in world output	Jaccard for collaboration with Russia
USA	52.3	57.4	0.9	8.9	31.1	0.8
Germany	42.6	11.1	3.7	9.3	8.0	2.6
UK	25.6	13.5	1.8	3.7	8.7	0.9
France	25.0	7.0	3.3	4.7	5.7	1.6
Italy	18.9	4.8	3.4	3.0	4.3	1.3
Japan	16.6	5.8	2.5	2.7	8.2	0.7
Switzerland	15.1	4.0	3.1	1.7	1.8	1.1
Netherlands	14.5	4.5	2.7	1.7	2.5	0.9
China	13.7	5.1	2.3	1.2	7.2	0.4
Poland	13.2	0.9	7.6	1.9	1.5	1.3

To give an estimate of the relative activity of collaboration between Russia and other countries, Jaccard indices for coauthored highly cited papers and all papers are given in Table 2. Except for the United States, all indices are significantly higher for high-impact articles. This proves the previous statement that international collaboration plays a greater role in world-class research. Especially remarkable is this indicator for Poland, as its Jaccard index for collaboration with Russia reaches 7.6%. This means that every 13th highly cited paper written by Russian or Polish scientist is jointly written.

TABLE 3. Russia as a collaborator. Share of highly cited papers/all papers written by different countries in collaboration with Russia.

	% in collaboration with Russia	
Country	Highly cited papers	All papers
USA	0.92	0.83
Germany	3.91	3.39
UK	1.93	1.22
France	3.65	2.42
Italy	4.00	2.06
Japan	2.92	0.98
Switzerland	3.80	2.79
Netherlands	3.27	2.00
China	2.73	0.49
Poland	15.17	3.70

Table 3 shows the inverse relation between Russia and its partners: what the share of papers written in coauthorship with Russian scientists is in a country's output. All shares are lower than their counterparts from Table 2 (Poland is the only exception). This means, in a sense, that Russia is a less important partner for these countries than these countries for Russia (as in highly cited papers, so in total output). Greater shares in the highly cited column of Table 3, compared to "all papers", illustrate once more the higher level of interdependence between different nations in high-impact research.

Additionally, what is important, is that collaboration with any country from Tables 2 and 3 increases the probability of a Russian paper becoming highly cited above the world average. For example, among Russian articles written in coauthorship with scientists from the United States, 2.1% have become highly cited (six times more often than the average Russian paper). Collaboration with Germany results in 1.6% of high-impact papers, with the United Kingdom 2.5%, France 1.9%, and so on. On average, 0.95% of internationally coauthored Russian papers become highly cited, which is very close to the world average value of 1%.

Russian institutions and leaders among them

A total of 259 Russian organizations authored at least one highly cited paper. Of them, 128 are institutes of the RAS or RAMS, 45 are "non-RAS" institutes and research centers, 43 are higher education institutions. The remaining 43 organizations, which do not fall into this classification, include commercial companies, state enterprises, hospitals, museums, and so on, and are referred to as "other" (here we even have one home address!).

The majority of highly cited papers, 547, were authored by institutions located in Moscow. Organizations located in the Moscow region (outside Moscow itself) have published 251 high-impact articles. Then follows Saint Petersburg (145, without its region which accounts for 63 papers), Novosibirsk, with its region (79) and Tomsk, with its region (22). Institutions from only 34 of 83 Russian regions authored at least one highly cited paper. Russian scientific "centers of excellence" are highly concentrated around "two capitals" (Moscow and Saint Petersburg); the only possible exception is Novosibirsk, a large scientific city, where the Siberian Branch of RAS is centered and Novosibirsk State University, one of the leading Russian universities, is located.

Table 4 shows Russian organizations, subdivided by type, which have published not less than 20 highly cited papers. Almost all research organizations in Table 4 are physics institutes, which is only natural considering that the majority of Russian highly cited papers belong to this discipline. The only exception is the Russian Cancer Research Center with 22 papers in medicine, although it has less than 10% average share in institutional coauthorship.

TABLE 4. Russian institutions with not less than 20 highly cited papers (in terms of whole counting).

Organization	Papers (whole counting)	Papers (fractional counting)
Russian Academy of Sciences / Medical Sciences		
Konstantinov Petersburg Nuclear Physics Institute, RAS	62	6.2
Lebedev Physical Institute, RAS	54	12.5
Ioffe Physical Technical Institute, RAS	45	14.7
Budker Institute of Nuclear Physics, RAS (Siberian Branch)	39	2.1
Institute for Nuclear Research, RAS	29	8.2
Landau Institute for Theoretical Physics, RAS	28	11.0
Blokhin Russian Cancer Research Center, RAMS	22	2.1
Total for all RAS/RAMS institutes:	**585**	**172.8**
Non-RAS institutes		
Joint Institute for Nuclear Research	116	12.0
Institute for High Energy Physics	81	3.5
Institute for Theoretical and Experimental Physics	79	13.1
National Research Centre "Kurchatov Institute"	55	8.9
Total for all non-RAS institutes:	**282**	**50.4**
Universities		
Lomonosov Moscow State University	108	36.1
National Research Nuclear University MEPhI	40	6.25
St. Petersburg State Polytechnical University	20	0.43
St. Petersburg State University	20	5.22
Total for all higher education institutions:	**263**	**78.7**

Nuclear physics as a field of specialization dominates in Table 4. However, Russian nuclear physics institutes generally have a small authorship share in highly cited papers; some of them account for only 10% of affiliations on average or even less. If we apply fractional counting, the leading position among all research institutions goes to Ioffe Physical Technical Institute, whose scientific profile is broader, including several high-impact papers in condensed matter physics, optics, and nanoscience.

The largest university in Russia, Moscow State University (MSU), heads the list of higher education institutions and, in terms of fractional counting, the list of all Russian organizations. Almost every ninth Russian first-class paper is (co)authored by scientists from MSU. It is followed by "MEPhI", which again has a strong focus on nuclear physics. Two St. Petersburg universities close this section. All four leaders have special status in the Russian higher education system. They are either “Federal Universities” (MSU, SPbSU) or “National Research Universities” (MEPhI, SPbSPU), which carry out special government programs and enjoy a higher level of government support (Berdashkevich, 2011; Guriev, 2009; Kiroi, 2011; Schiermeier, 2010). This is not the case for the subsequent ranks: Universities occupying fifth (Tomsk State Pedagogical University) and sixth (Ufa State Aviation Technical University) positions have not gained any special status.

According to Table 4, in general the share of universities in institutional collaboration is greater than that of research institutes. But here the picture is far from homogeneous again. Surprisingly, two St. Petersburg universities that have published the same number of highly cited papers show diametrical contrast, with a 26% average share in authorship for classical university and 2% for technical one.

As for “other” organizations, which do not fall into the classification of Table 4, each of them has published no more than 3 papers. Their overall contribution is more than modest, 46 papers (10.3 by fractional counting). This demonstrates that the role of the commercial sector in producing high-impact papers is almost negligible in Russia.

Collaboration between Russian institutions

We find intranational coauthorship between Russian organizations in 259 of 927 highly cited papers (28%). Among those papers that involve intranational collaboration, the majority (140 papers) have only two Russian institutions in the list of affiliations. There is one paper that is coauthored by 10 Russian organizations: It is in biology/biochemistry.

The average number of Russian institutions in all Russian highly cited papers is 1.51. Interestingly, if we consider only papers where *all* authors are from Russia, this number will change only marginally (1.56). This means that international collaboration does not seriously affect the intensity of intranational one.

Among disciplines, physics, biology, and engineering are the most “intracollaborative” in terms of the average number of Russian institutions; chemistry and space science are the least. The former three disciplines also have the smallest proportion of articles with only one Russian affiliation (as usual, here we limit ourselves to the disciplines with more than 20 papers).

Table 5 shows the structure of coauthorship in highly cited papers between different types of Russian institutions. We observe a concentration of intranational collaboration around research institutes. They generally publish highly cited papers in cooperation with each other more often than with universities. Higher education institutions show a significant share of intracollaborative papers, but almost all of them are in coauthorship with research organizations. Only 12 highly cited papers involved two different universities as partners, less than 5% of the total higher education sector high-impact output. In total, the research/higher education partnership produced 109 papers, which makes up 89% of the universities' intracollaborative output and 45% of that of the research institutes. Despite serious efforts made by the Russian government to stimulate university science during the last decade (Schiermeier, 2010, 2012), now research institutions remain more important internal partners for universities than vice versa.

TABLE 5. Intranational collaboration, by type of institution.

Type of institution	Total intra-collaborative	RAS/RAMS	Non-RAS	H.E.
RAS/RAMS	33	10	19	13
Non-RAS	58	40	35	28
Higher education	46	28	30	5

For each institution type the share of all intra-collaborative papers and shares of papers published in collaboration with different types of Russian institutions are shown (%).

As for the "other" organizations, they produced the majority of their highly cited papers (63%) intracollaboratively. If we look at the output of the commercial organizations within the "other" category, we find that there are only eight papers coauthored by research institute, one by a university and two by organizations of both types. Cooperation between commercial and the research/education sectors inside Russia is low.

Figure 2 shows the map of intracollaboration between Russian institutions in producing highly cited papers. The more papers co-authored by institutions, the less is the distance between them. We left only institutions with not less than 20 high-impact papers. Additionally, two organizations with only one paper written in collaboration with some of the other institutions from Figure 2 were omitted.

Papers in all disciplines were taken into account, but the vast majority of them were in physics. The exception is 15 articles published in engineering journals, they were explored one by one. Due to their interdisciplinary nature and closeness to physics their addition does not distort the homogeneity of the map.

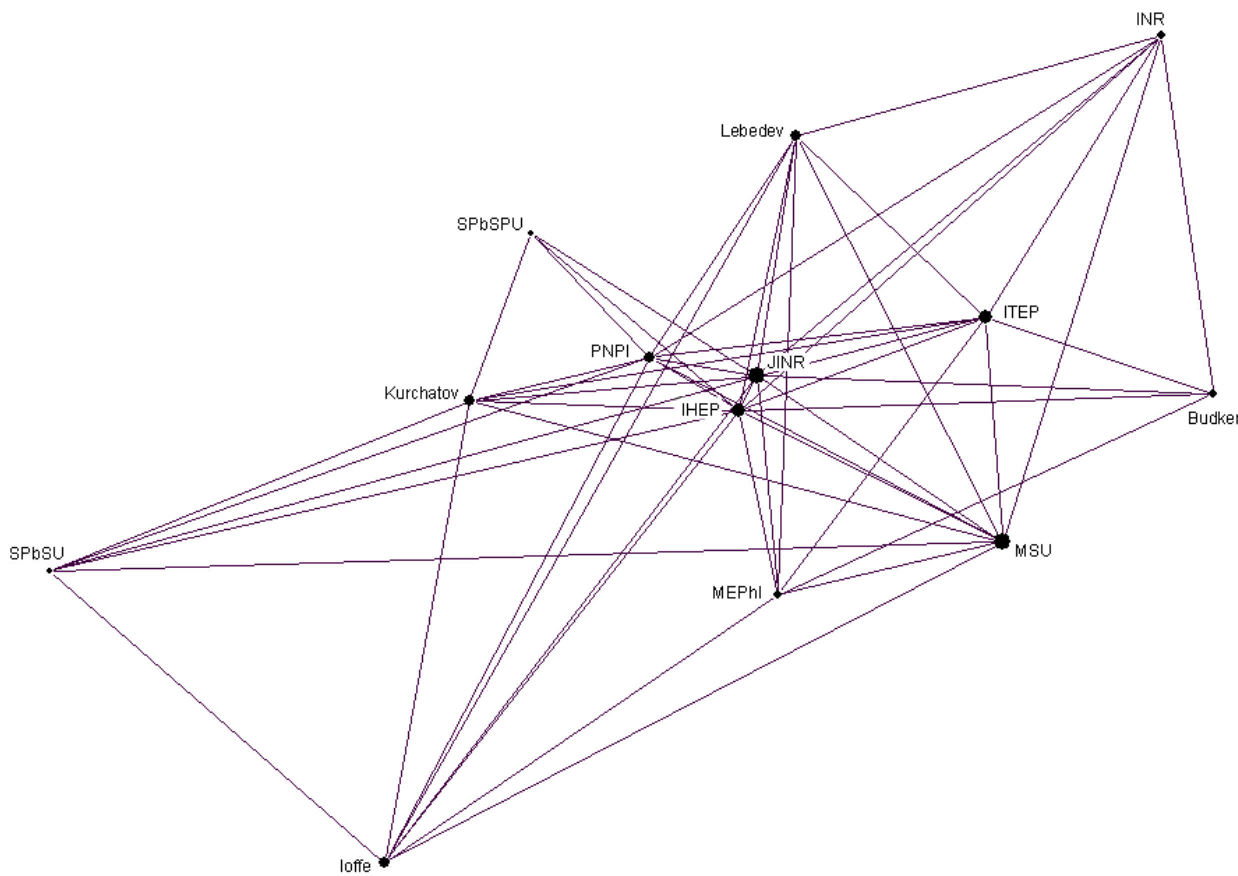

FIG. 2. Collaboration between Russian institutions in highly cited papers. The size of the node corresponds to the total number of highly cited papers published by the organization. Line between two institutions shows that they have at least one joint highly cited paper. Proximity of nodes to each other reflects the number of highly cited papers coauthored by organizations. Budker = Budker Institute of Nuclear Physics (SB RAS, Novosibirsk); IHEP = Institute for High Energy Physics (Moscow reg.); INR = Institute for Nuclear Research (RAS, Moscow); Ioffe = Ioffe Physical Technical Institute (RAS, St. Petersburg); ITEP = Institute for Theoretical and Experimental Physics (Moscow); JINR = Joint Institute for Nuclear Research (Moscow reg.); Kurchatov = National Research Centre "Kurchatov Institute" (Moscow); Lebedev = Lebedev Physical Institute (RAS, Moscow); MEPhI = National Research Nuclear University MEPhI (Moscow); MSU = Lomonosov Moscow State University (Moscow); PNPI = Konstantinov Petersburg Nuclear Physics Institute (RAS, St. Petersburg reg.); SPbSPU = St. Petersburg State Polytechnical University (St. Petersburg); SPbSU = St. Petersburg State University (St. Petersburg).

Several properties of the internal collaboration between Russian institutions are clearly illustrated by the map:

- the center is occupied by three research institutes which form the backbone of the network. These are the Institute for High Energy Physics, Joint Institute for Nuclear Research, and Petersburg Nuclear Physics Institute, all focused on nuclear and particle physics;[8]
- except for PNPI case, the geographical segregation is easily seen. Other Petersburg institutions (Ioffe, SPbSPU, SPbSU) as well as the only one from Novosibirsk (Budker) are found at the periphery of the map;
- there are weak collaboration ties between universities. In most cases they are closer to research institutes than to each other;
- in general, the level of collaboration with other Russian organizations is higher for research institutions than for higher education sector. As a result, even MSU, which ranks second in terms of the number of highly cited papers, is not positioned very close to the center of the collaboration map.

Conclusion

A number of studies have reported that Russian scientific productivity lags behind the global trend, for example, see the most recent work of Kirchik, Gingras, and Larivière (2012). Our analysis extends these conclusions, showing that the lag is particularly noticeable in the upper part of the pyramid of science, where, in the word of Bonitz (2002, p. 442), “the Olympic games in science” are held. There is no easy solution to improving the situation; obviously, major changes in overall Russian science policy are needed. If we compare our results with those of Narin et al. (1983), we may assume that in terms of highly cited papers the relative position of Russia has slightly improved since 1970s. But all “centers of excellence” have remained the same. Among the research institutions in Table 4 the only exception is the Budker Institute of Nuclear Physics, which was not listed by Narin et al. “First-class science” continues to be produced in the old renowned ex-Soviet research centers.

[8] One may notice that none of the three is located directly in Moscow or St. Petersburg, the cities with the greatest number of highly cited papers. Surely, it is a consequence of their field of study. Large nuclear centers with their infrastructure are located in the suburbs.

The widely accepted view is that international collaboration is almost a requirement for publishing highly cited papers. This pattern is probably true not only for scientifically peripheral countries. For example, Daraio and Moed (2011, p. 1385) conclude that for most European Union countries "the quality of scientific production goes hand-in-hand with international collaborations". However, our study shows that in the case of Russia this correlation reaches its extreme, when only 8% of highly cited papers are written exclusively by Russian authors. To some extent our study implies that all "successfulness" or "unsuccessfulness" of the discipline may reflect the degree of international partnership in it, as was shown for medicine, chemistry, and mathematics. This effect may be observed not only for highly cited papers, but also for citedness of the "ordinary" publications; for example, Pislyakov and Dyachenko (2010) have demonstrated it for Russian articles in physics and chemistry.

Thus, if we tried to formulate, on the basis of the present study, some recommendations for policy makers, the first would be to reinforce collaboration with the leading foreign centers. The quest for excellence should be international. Second, the collaboration between Russian research centers which tend to publish a significant number of highly cited papers together (e.g., those that form "the triangle of successful collaboration" on our map) should also be encouraged. These are two points in the category "how to make the good better". If we had to put forward something in the "how to improve the bad" style, we would suggest that cooperation between Russian universities be strengthened, especially in the high-impact research. This type of collaboration, at the moment severely underrepresented in the highly cited Russian papers, also has strong potential for advancement of the national system of science and education.

Finally, we have to return to a remark, made in the Introduction, on the coverage of national journals in the Thomson Reuters databases. When analyzing the serious lag of Russian science reflected in the relative number of highly cited papers, one should keep in mind that there are more than a hundred Russian journals in the Web of Science that have not published a single high-impact article for 10 years. As these journals generally publish papers by Russian authors, they seriously affect relative performance indicators of Russian science. This must be taken into consideration when interpreting the underperformance, especially the low percentage of Russian papers becoming highly cited. Moreover, today there is a "Web of Science boom" in Russia, when science policy makers, scientists, and journals themselves strive for more Russian journals to be indexed in the Thomson Reuters databases, so it is important for them to be aware of the probable side-effect: The growing number of indexed Russian journals will cause national output indicators to rise, but impact indicators to drop. After all, as Zitt et al. (2003, p. 280) put it

> "A large publication share with a low impact" can in some contexts give a poorer picture of a national output than "a smaller publication share, with a better impact performance".

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