Nanotechnology Research in Post-Soviet Russia: Science System Path-Dependencies and their Influences

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Abstract
This paper contributes to the analysis of Russian research dynamics and output in nanotechnology. The paper presents an analysis of Russian nanotechnology research outputs during the period of 1990-2012. By examining general outputs, publication paths and collaboration patterns, the paper identifies a series of quantified factors that help to explain Russia's limited success in leveraging its ambitious national nanotechnology initiative. Attention is given to path-dependent institutionalised practices, such as established publication pathways that are dominated by the Academy of Sciences, the high centralisation of the entire research system, and issues of internal collaborations of actors within the domestic research system.

Conference Topic
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Introduction
Nanotechnology has been an interest of bibliometric research since the early 2000s after the United States and China adopted large-scale policy and funding programmes to stimulate scientific development by massively investing in this interdisciplinary research area. China has been among the countries with a large increase in research outputs in nanotechnology, and is the emerging economy that is frequently the focus of researchers (Appelbaum et al., 2011; Bhattacharya & Bhati, 2011; Liu et al., 2009).

Other emerging and transitional economies have also invested in nanotechnology development. Russia is a particular case among these countries, because the National Nanotechnology Initiative that was adopted in 2007 was a political as well an economic, scientific and technological project. The Russian government picked up on global trends and invested greatly in development of nanotechnology. On a purchasing power basis, it is suggested that public investment in Russian nanotechnology has rivalled that of the US and China (Schiermeier, 2007). Lux Research (2013) estimates that Russian nanotechnology investment has consistently been the third largest in the world after the US and China: Russia invested over $1 bln in 2010 and 2011 in nanotechnology projects, and just under $1 bln in 2012. However, with lower than anticipated results in nanotechnology, the Russian government has decreased its investment programme and the share of Russia in world nanotechnology funding dropped from 15% to 13% in 2013. It is anticipated to continue decreasing.

Important changes and structural reforms of Russian science (including nanoscience) have been implemented only relatively recently, in the mid- to late-2000s, almost two decades after the dissolution of the Soviet Union in 1991. Until then, Russian science was relatively unchanged from rules and institutional developed during the Soviet era. The Academy of Sciences of Russia maintained its Soviet-style organisation up until 2013 when it was subjected to a radical reform. Universities were reformed in 2008 and 2009 to move them away from mainly teaching and to develop research capabilities and to try to emulate US research clusters. The funding structure for Russian science was tied to four-year umbrella research programmes accompanied by small-scale research foundations until 2013, when decisions were made to reform Russia's Federal Targeted Programmes and Grant

Programmes towards more grant-based system. Importantly, the Russian National Nanotechnology Initiative and the associated surges in interest and investment pioneered the system-wide initiatives that started several years before other large-scale top-down changes.

Existing literature on nanotechnology research and innovation in Russia is less prodigious than for other “Rising Powers” countries, particularly China but also including Brazil and India. Scientometric analyses often examine Russian nanotechnology development as a benchmark for other emerging economies, mainly China and India (Liu et al., 2011, 2009) rather than deeply probing within the Russian system. At the same time, there is an important strand of scientometric work on Russian science and technology (including nanotechnology) produced by the Russian research community itself. In these cases, research is often descriptive or addresses internal debates within Russia (Terekhov, 2012, 2011), and sometimes lacks a critical approach. Additionally, most of these studies remain mostly background reference country reports (and are frequently only available in Russian).

There are, of course, some exceptions. For example, Klochikhin (2012) contextualised Russian nanotechnology policy in terms of post-Soviet path-dependencies and asked whether it was possible to break out from technological inertia to a new development trajectory. There are other studies of Russian nanotechnology that pose similar questions, be it from the industry and market formation perspective (Ananyan, 2005), or regulation (Gokhberg et al., 2012). A recent overview of the Russian Science, Technology and Innovation system (Karaulova et al., 2014) provides background for discussion of persisting path-dependencies. In the present paper, we build on, and extend, this prior work to examine Russia’s technology development policies and to reflect on the challenges posed by its persistent and deeply-embedded path-dependent practices.

Data and Methodology

The dataset for our research covers the time period from 1990 to 2012, which includes the transitional period after the breakup of the Soviet Union, the Russian Nanotechnology Initiative (NNI) development (2004 – 2007) and the post-NNI period of nanotechnology research. We first provide an updated profile of nanotechnology research in Russia since the breakup of the Soviet Union until 2012. Second, we investigate the possible emergence of new trends of research of Russian nanotechnology after the adoption of large-scale policy programs. Third, we use self-reported publication data in order to illustrate the path-dependent nature of Russian nanotechnology research.

The bibliometric analysis draws on datasets of nanotechnology publications and patents developed by researchers at Georgia Institute of Technology and the Manchester Institute of Innovation Research. Two data sources are used: the Web of Science (scientific publications) (WoS) and Derwent Innovations (patents). Both data sources are published and made available in the Web of Knowledge by Thomson Reuters. Nanotechnology records in the databases are identified using the two-stage search strategy detailed in Porter et al. (2008), and updated in Arora et al. (2012). A keyword search based on a Boolean query is applied. Unrelated records are then removed by applying exclusion terms.

The defining characteristic that we used to identify Russian publications was that at least one author of each included publication had to have a Russian affiliation address (Soviet Union in 1990-1992; Russia subsequently). The primary language of publications in the dataset is English, but specialised editions that include translated articles originally published in Russian are included as well. In total 33,538 Russian nanotechnology publication records were identified in 1990-2012. We acknowledge that there are limitations in using WoS for capturing the totality of Russian science activity (but see also subsequent discussion in this paper of Russian journal publishing strategies).

A feature of the Soviet Union, carried over into the Russian Federation, is that science was and is developed in parallel – but not always in cooperation – with researchers elsewhere in the world. This influences the choice of terminology used by Russian researchers. For example, it has been observed that there is a rich tradition of nanotechnology research in Russia. Alexander Terekhov traces the technological development of Russian nanotechnology back to 1980s when the understanding of the physical properties of ultra-dispersed states enabled Soviet researchers to construct the first lasers and to conduct experiments at the nano-scale (Terekhov, 2013). But the term nanotechnology was not necessarily used at that time. A simple search strategy would not pick up on many Russian nanotechnology publications, especially in earlier years, which are crucial to understand trends of overall growth and development. We judge that the more complex and nuanced approach we apply is better able to capture the emergence and development of the Russia nanotechnology field.

After the publication data was collected and cleaned from unrelated records, further data cleaning to remove duplicates and consolidate organizational and author names was undertaken using VantagePoint text mining software. Cleaning is a large part of our methodology. One of the biggest problems of country report studies that use bibliometric analysis is the issue of varied affiliation reporting. We have addressed various problems through intense cleaning of the data. One problem of aggregation relates to affiliation (location, funding source, author) categories that the database recognizes as separate, but are actually the same. This is an issue that occurs in the self-reported semi-structured publication data. There are variations in reporting of affiliation data, different ways to spell the name of the organization, abbreviations and others. If left unchallenged, the data may be potentially distorted: the contributions of certain actors may appear as less than it reality, which can be misleading. Another major cleaning issue is disambiguating terms that were lumped together. For example, the process of disambiguation of the "Tech Univ" field and further aggregation of the items highlighted that the original very general field contained mainly records published in three large technical universities, and in a number of smaller ones. Table 1 illustrates examples of the data cleaning strategy.

Table 1. Affiliation Cleaning Strategy Examples.

	Original Record	*Cleaned Record*
Reporting Style	1. RAS, AM Prokhorov Gen Phys Inst; 2. Russian Acad Sci IOF RAN, Prokhorov Gen Phys Inst;	RAS Inst Gen Phys Prokhorov
Abbreviation	1. MISIS 2. State Univ Moscow Inst Steel & Alloys	Natl Univ Sci & Technol MISIS
Spelling	1. Alfa Akonis Res & Devices Enterprise 2. Alpha Akonis R&D Enterprise	Alpha Akonis R&D Enterprise
Change of Name	1. Leningrad State Tech Univ 2. St Petersburg State Tech Univ	St Petersburg State Tech Univ
Disambiguation	Tech Univ	1. St Petersburg Tech Univ 2. Tech Univ Moscow Inst Elect Technol 3. Tech Univ Berlin

Excessive aggregation of the data may lead to the loss of informative value. The Russian Academy of Sciences (RAS) presents the greatest challenge here. RAS is a large research organisation that possesses more than 500 research institutes. However, the reported RAS affiliations are disordered, because research institutes often have long names and some of them do not issue guidelines for official English versions. Aggregating all these institutes under the domain of the "Russian Academy of Sciences" would yield analytical benefits in some circumstances, such as broad benchmarking. However, such a large agglomeration is not useful for detailed analysis. In our analyses of nanotechnology publications associated with RAS, we undertook disambiguation and identified 263 distinct affiliations, including research institutes of RAS, scientific centres and observatories.

We further grouped the data according to country, region, and type of affiliation. *Academy of Science* organisations are specific research entities that have wide government affiliations and heavily rely on government funding, that have a wide regional structure and hierarchical administrative division. We separately distinguished *Universities*. *Public Research Organisations* are private and state-owned research institutes that are neither academy of science institutions, nor universities. These also include research foundations and ministries. *Corporate actors* are privately and state-owned company affiliations. Organisations were usually labelled as 'corporate' actors if they had a distinctive property type word in their names (LLC, Ltd, GmbH, ZAO etc). *Other* included all other organisations that could not be attributed to any other category

In order to examine the internationalisation of Russian science we also separated publications into nationally collaborated publications (NCP) and internationally collaborated publications (ICP). The two groups are mutually exclusive and highlight the degree to which research produced in Russia only involves domestic actors (NCP), or there are also international partners (ICP).

Table 2. Grouping Results, number of publications.

Internalisation			*Domestic Affiliation Groups*			
				Orgs	Pubs	Share
			Acad of Sciences	3+1(263)	22927	68.5%
NCP	19098	56.9%	University	396	13868	41.4%
ICP	14440	42.8%	PROs	432	3781	11.3%
			Corporate	420	982	2.9%
			Other	3	3	0%

Results

The annual output of Russian nanotechnology publications steadily increased between 1990 and 2012. In 1998, there was a considerable jump in the number of publications; this probably reflects the fresh inclusion of a series of Russian journals within the WoS. Growth rates for domestic and international publications are almost identical starting from 1999 until 2012 and are about 1.1% per year. On average, domestic publications grow 2% faster than internationally collaborated publications.

The Academy of Sciences, 15 universities and four State Research Institutes are the leading organisations in terms of publication output. Some 68% of domestic publications are produced by the Russian Academy of Sciences and another 12% by Moscow State University. The top five organisations produced together 80% of all publications in 1990-2012 (Table 3). The top three organisations (RAS, MSU and St Petersburg State University) produced 78% of all publications. RAS is the dominant actor in producing nanoscience publications. However, in terms of annual publication outputs, university researchers have been catching up with RAS in the past decade.

Table 3. Biggest Publishers in Russian Nanoscience, 1990-2012.

	Organisation name	*Publications*	*Share*
1	Russian Academy of Sciences	22794	68.12%
2	Moscow MV Lomonosov State University	4007	11.98%
3	St Petersburg State University	1208	3.61%
4	Russian Research Centre Kurchatov Instute	613	1.83%
5	Nizhnii Novgorod State University	496	1.48%

Disambiguated, the bibliometric map of Russian science demonstrates a more nuanced picture of interactions in the nanotechnology research (Figure 1). One major research organisation, RAS Institute of Physics and Technology n.a. Ioffe, is a focal point for connecting various regional groupings of research centres, such as a cluster of four RAS institutes on Siberia that closely collaborate with one another, but do not have strong external links.

In terms of research performance, nanotechnology publications that only have Russian authors are cited on average 2.5 times per publication. Out of all domestic actors Russian Academy of Sciences publications collect the highest number of citations: 4.55 p/p. PRO publications, albeit being much smaller in number, collect 3.86 citations p/p. Universities collect on average 3.24 citations p/p, and publications produced by corporate actors collect 2.44 citations p/p.

Table 4. Shares of ICP and Average Citation Rate of Russia's Main Collaboration Partner Countries, 1990-2012.

Country	*Germany*	*USA*	*France*	*UK*	*Japan*	*Sweden*	*Italy*
ICP %	12.3%	8.2%	5.04%	3.4%	2.9%	2.08%	1.9%
Avg Cit	7.7	9.2	5.8	12.2	6.9	6.04	5.3
	Ukraine	*Poland*	*Spain*	*Netherlands*	*Belarus*	*Finland*	*South Korea*
ICP %	1.8%	1.5%	1.5%	1.4%	1.3%	1.1%	0.9%
Avg Cit	2.4	3.9	5.1	18.9	3.8	4.05	3.9

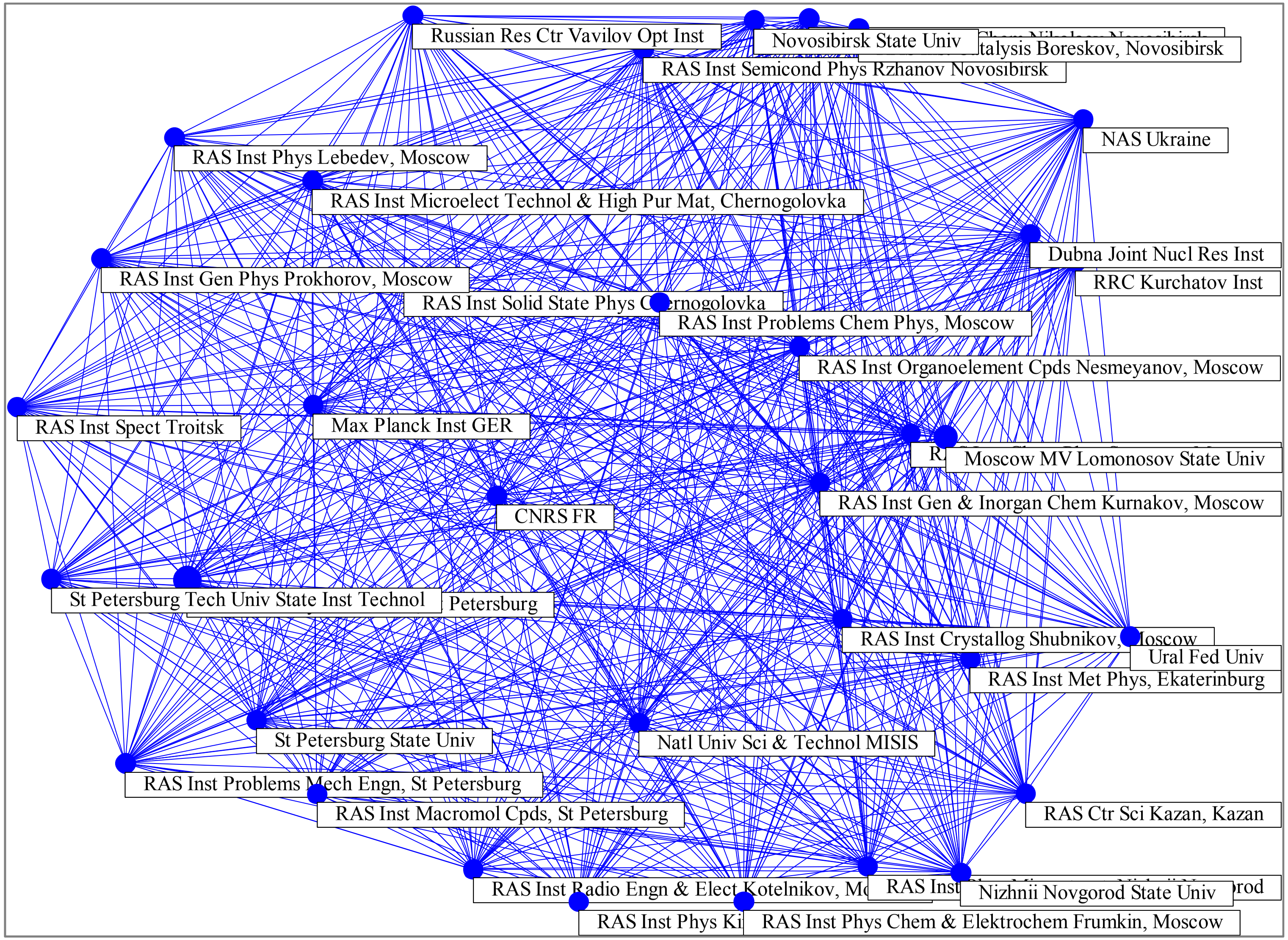

Figure 1. Bibliometric Map of Top 35 Publishers of Russian Nanoscience, 1990-2012.

Patterns of international collaboration seem to be connected to these structural differences. The average number of internationally cited publications is 4.33 times: international collaboration increases average citation by 1.7. There are, however, some regional variations in international collaboration performance outputs (Table 4). Russian international collaborations have strong European orientation, and there is evidence of recurrent path-dependent practices. It is noticeable that former Soviet states and influenced territories, such as Ukraine, Poland and Belarus factor highly in collaborative research. It implies research links are built on the older networks than the current political system and research takes place through these interactions. An impeding factor may be than average citation rates for these countries are significantly lower than for other countries with the same collaboration intensity (refer to Table 4). These 8.3% of CIS-collaborated ICPs represent collaboration patterns that may be detrimental to Russian science.

In the next section we pay particular attention to three elements of nanotechnology research that can highlight path-dependent dynamics of scientific knowledge production in Russia. We define them as journal gatekeepers, centralisation, and institutional diffusion. These all relate to structural features of the Russian science system that have persisted even after the Soviet Union broke apart.

Journal Gatekeepers

The data for journals in which Russian co-authored publications can be found, is available for 32844 publications, which constitutes 97% of the data. The majority of Russian publications in English were published in translated journals. Out of the top-10 journals with the biggest number of Russian publications, 7 are translated versions of Russian journals (refer to Table 5).

Translated versions of Russian journals are identified not by the publishing body (the rights to publish in most cases are owned by Springer), but by the contents of the journal and the editorial board. For example, Springer publishes *The Physics of the Solid State*. The description on the website says "The journal Physics of the Solid State presents the latest results from Russia's leading researchers in condensed matter physics at the Russian Academy of Sciences and other prestigious institutions" (Springer, n.d.). An analogous journal, called *Phyzika Tvyordogo Tela* (*The Physics of the Solid State*) is published in Russian by the Ioffe Institute in St.Petersburg (Ioffe Physical Technical Institute, n.d.). The Chief Editor of both journals is A.A. Kaplyanskii, and the editorial board matches both journal records. Tables of contents of issues match as well. Based on these we drew a conclusion that *The Physics of the Solid State* is a translated version of *Phyzika Tvyordogo Tela*, and the 'publishing body' is therefore an Institute within the Russian Academy of Sciences (the publishing body of the original), not Springer (the publishing body of the translated version). By doing manual analysis of the top journals in which Russian scientists publish we have identified that at least 25% of the entire publication volume was published in this manner (input of the Russian translated journals in the top-20 journal contributions). The overall contribution of the top-20 journals was 25%.

A paper is first published in a Russian peer-reviewed journal, and subsequently translated and published in the English version without an additional peer review. But it would also depend on the domestic peer reviewer whether a submitted article would be considered for publication and further translation for a WoS-indexed version of a journal. The publisher and the editorial board become important. As Table 5 demonstrates, vast majority of the translated Russian journals are published by the Russian Academy of Sciences and editorial boards mainly consist of members of RAS. This *status quo* is grounded in history: many of them were founded during the Soviet Union to inform the world about achievements of Soviet science.

Table 5. Top 20 Journals of Russian Nanotechnology.

	Journal	*Publishing Body*	*Records*	*Share*
1	Physical Review B	APS	1595	4.86%
2	Physics of the Solid State	RAS	1412	4.30%
3	Semiconductors	RAS	1255	3.82%
4	Technical Physics Letters	RAS	848	2.58%
5	JETP Letters	RAS	828	2.52%
6	Inorganic Materials	RAS	511	1.56%
7	Applied Physics Letters	American Institute of Physics	510	1.55%
8	Journal of Applied Physics	AIP Publishing	505	1.54%
9	Journal of Experimental & Theoretical Physics	RAS	490	1.49%
10	Russian Chemical Bulletin	RAS	411	1.25%

After the breakup of the Soviet Union, these established publication pathways and journals have been maintained and there has not been much impetus for change. Although an opportunity opened for Russian researchers to submit research publications to leading international journals, existing publication practices have persisted. Moreover, temporal dynamics highlight an increasing gap between publications submitted to translated Russian journals and international journals: the difference rose from twice as many translated journal publications as international journal publications in 2000 to 2.67 times in 2005 and to 3.8 times in 2011. In the earlier period this could have been explained by the lack of experience of researchers to publish abroad, or by poor knowledge of English. In the later period the English language problem continues, but it also has become prominent that internal domestic recognition for a Russian researcher can be even more important than international recognition in order to develop and continue a research career in Russia. Therefore, publishing in top domestic journals becomes a priority, and the English translation of these papers in journals that collect few citations is a by-product rather than the goal, because this research is anchored in Russian scientific discourse and debates.

RAS maintains the monopoly over acceptance of research outputs to the leading domestic journals, thus acting as a quality control body. It is also a gatekeeper in the Russian research system as to which domestic researchers are highlighted for international recognition. The domination of the Academy of Sciences constrains other research performers, such as universities and PROs, to develop and take advantage of publicly-provided research resources, for example through the Russian NNI. As a comparison, in their study of Chinese publication patterns Zhou and Leydesdorff (2006) recognised this 'gatekeeping' role as one of the main barriers to internationalisation of Chinese science in the early 2000s. However, this pattern has now changed with the emphasis in China in publishing directly in WoS journals.

Centralisation and the Academy

In our analysis, we observe two centralisation trends in publications within the Russian Academy of Sciences. These first of these is *geographical centralisation*. RAS has institutes in all 83 regions of Russia, but four regions (Moscow, St Petersburg, Novosibirsk, and the Moscow Region) produced the largest shares of publications in 1990-2012, contributing over 80% of the total amount. Moscow is the leader with almost 35% of all publications, together with the Moscow Region the agglomeration produced 45.2% of all Academy of Sciences publications. Previously, the high concentration of research in a limited geographical area and with a large network of ineffective and low-performing institutes has been suggested to be one of the main reasons for the persistent problems of RAS (Graham, 1998).

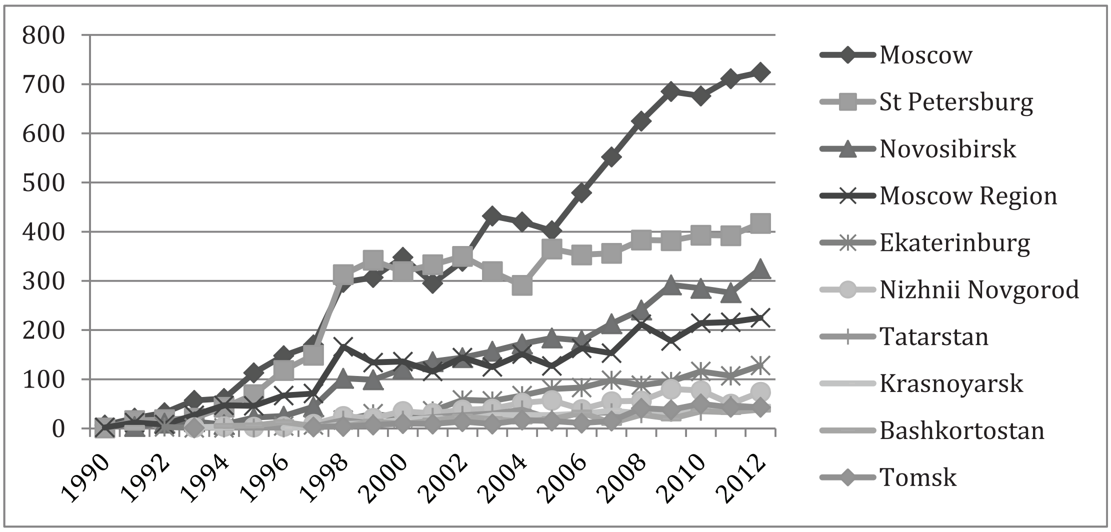

Figure 2. Temporal Dynamics of Geography of Nanoscience in Russia, 1990-2012.

Yet, while problems of RAS centralisation have long been observed, it seems that these trends have intensified in recent years: Academy research is becoming even more centralised (Figure 2). In nanotechnology, RAS institutes in Moscow surged upwards in the mid-2000s, producing almost twice as many publications in 2012 as the research cluster in St Petersburg. Many of these institutes have benefited from recent government science and innovation funding programmes, including specific nanoscience and nanotechnology funding programmes.

The *centralisation of high quality research* is a second persistent trend in Russian nanoscience. RAS has consistently contributed about 70% of the Russian annual publication output. In order to investigate whether quantity translates into quality, we assessed the performance of Russian domestic research system according to the criteria of (1) what affiliations of 10 top-cited ("star") scientists are, and (2) what affiliations of 100 top-cited publications are.

The top 10 most productive researchers coincide with the most cited researchers, with slight reversal in rank.[1] The majority of these "star" scientists are affiliated with RAS Ioffe Physical Technical Institute in St. Petersburg (Table 6). The Institute itself contributed about 14% of all publications and has an average citation of 6.13. The peak publication activity of all of the most productive scientists was between 1998-2000 after which the decline started. The most productive periods of the most productive Russian nanoscientists coincide with the most productive periods of Russian nanoscience: the contribution of "star" scientists was above 9% in 1996-2001, reaching a peak of 11.5% in 1998. A second, smaller, peak is reached in 2006, after which further decline occurs.

[1] The most highly cited Russian scientists are the ones who collaborated with colleagues at the University of Manchester in a paper in *Science* (Novoselov et al., 2005) that contributed to the award of the 2010 Nobel Prize in Physics to two Manchester researchers. This publication has 3541 citations. To include this exceptionally highly cited publication into the data would overshadow the underlying pattern of Russian nanotechnology performance, so this publication is not included in this part of the citation analysis.

Table 6. "Star" Scientists of Russian Nanoscience.

Rank	*Author Name*	*Affiliations*	*Times Cited*
1	Ledentsov, N	RAS Ioffe Physical Technical Institute	6033
2	Ustinov, Vr	RAS Ioffe Physical Technical Institute	5559
3	Alferov, Zh	RAS Ioffe Physical Technical Institute	5108
4	Kop'ev, P	RAS Ioffe Physical Technical Institute	5052
5	Zhukov, A	RAS Ioffe Physical Technical Institute	3504
6	Valiev, R	RAS Institute of Metals Superplasticity Problems; State Tech Univ of Aviation	3428
7	Egorov, A	RAS Ioffe Physical Technical Institute	2788
8	Morozov, S	RAS Institute of Microelectronics Technology & High Purity Materials	2323
9	Maximov, M	RAS Ioffe Physical Technical Institute	1909
10	Ruvimov, S	RAS Ioffe Physical Technical Institute	1812

The Post-Soviet period saw the rise and the peak of careers of scientists trained in the latter years of the Soviet Union. A drop in productivity coincides with the completion of the active research phase of their careers. There are few new ‘rising stars’ in the system, which explains the overall decline in performance. This data reinforces concerns about the ‘generation gap’ in nanotechnology where the average age of researchers is now in the mid-50s (Terekhov, 2011). RAS co-authored 81 out of the 100 most highly cited publications in Russian nanoscience.

Overall, it is notable that RAS dominates in quality as well as the quantity of research in Russian nanoscience. The productivity of RAS reached its peak in the late 1990s and has since then been in decline. The Russian government’s support of the development of research universities and RAS reform in 2013 are expected to further contribute to decentralisation of the national research system and to the emergence of new centres of excellence. The trend towards concentration of research in the two capitals – Moscow and St Petersburg – is also a concern as government support to develop scientific research in other regions is limited.

Institutional Diffusion

The third and the final collaboration trend reflects the institutional diffusion of the Russian research system. Institutional theory proponents argue that institutions last and prosper when other elements of the system are dependent on them, e.g. when institutions are diffused well with other institutions (Clemens & Cook, 1999). In a research system this mainly takes form of inter-institutional collaborations. In order to examine the institutional relationships of the Russian research system we investigated (1) whether each organisation preferred to publish on its own; (2) if research was done through the collaboration of authors in one organisation; (3) whether the organisation engaged in collaborative activities with other organisations of the same type; (4) if organisations collaborated nationally; and (5) whether organisations collaborated internationally.

The results of this analysis demonstrate various patterns of domestic collaboration (Figure 3). For instance, corporate publishers have to rely heavily on collaborations, so they have higher rate of collaborations with all types of actors than the average. An asymmetric relationship among the system actors reflects institutional domination of the Academy of Sciences of Russia. The analysis of institutional collaboration patterns demonstrates that there are very weak collaboration links between the Academy of Sciences and other system actors.

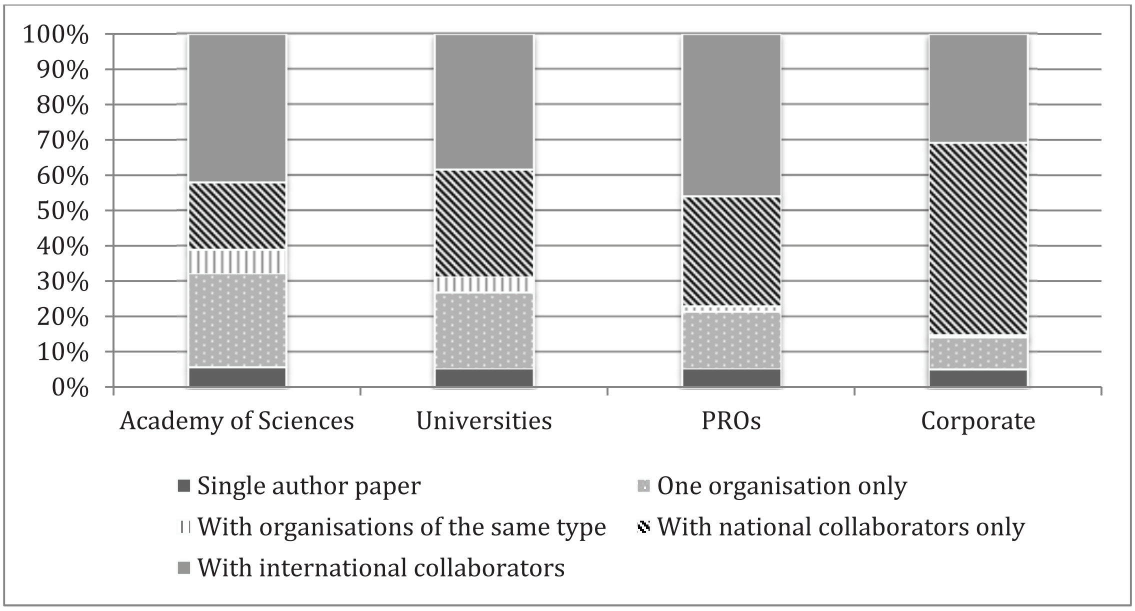

Figure 3. Institutional Diffusion of Russian Research System.

About two-fifths of academic publications are written either by a single author, or by a group of authors within RAS, and only 19% are collaborated with other Russian organisations. An international orientation is evident for PROs: over 46% of publications are internationally collaborated, but only 1.5% of publications are collaborated with other PROs. University organisations stand in the middle and have larger share of nationally collaborated publications than the Academy or PROs.

Weaknesses in international orientation and a reluctance to engage in national collaborative research projects is a particular concern for the Russian Academy of Sciences given that it dominates much of the Russian research system. In some RAS institutes, domestic collaboration rates with others outside of the home institute are noticeably low, for example just 11.6% in the Institute of Theoretical Physics RAS n.a. the Landau Institute of Theoretical Physics.

Conclusion

This exploratory study highlights three major path-dependent structural features of the Russian research system that are evident in Russia's nanotechnology research and publication activities. These structural features tend to be under-emphasized in other quantitative and qualitative studies, including those undertaken from within Russia itself. The available studies tend to focus on underfunding, deteriorating equipment, brain drain and other factors that, without a doubt, are very important in understanding the position of Russian science. In this research note, using bibliometric analysis in the case of nanotechnology, we draw attention to other less explicit but nonetheless important underpinning factors that frustrate the successful implementation of science and innovation policies and which may weaken returns on research investment. Reflecting upon and revising institutional practices of research that have remain largely unchanged since the breakup of the Soviet Union is an important challenge for Russian science policy. Some reform efforts have begun, but much more is likely to be needed to support the next generation of researchers.

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