Russian Science and Higher Education in a More Global Era

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Abstract. Much has changed in Russia since the end of the Soviet period, but in higher education and science, the world outside of Russia may have changed more than the world within. In the Internet era, all national research systems have become partly subsumed into a single English-language global science system while still retaining distinct national identities. Most innovations in technology and product development are now sourced partially or entirely from global sources. It is essential to become proficient at accessing global science, which means producing global science and collaborating with others. Russian science remains surprisingly decoupled from world science. Global publication and citation rates at Russia's leading universities are very low compared to those of their counterparts abroad. Between 1995 and 2012, international co-authorship of journal papers increased by 168 per cent at the world level—and grew by a factor of ten in China—but the number of internationally co-authored papers rose by only 35 per cent in Russia. The lack of internationalization of Russian universities and science, coupled with the continued erosion of the Soviet legacy, contributes to the country's weak performance in research rankings, both objectively—real research paper output is falling, and Russia has been left well behind by dynamic developments in China and the rest of East Asia, and to a lesser extent by Brazil and India—and subjectively—there are substantial national research strengths in areas like engineering, manufacturing, engineering and strategic industries, but as it is conducted primarily in Russian and not published in global journals, it is "invisible." Russia's national policy goal of having five of its universities enter the ranks of the top 100 in the world is a long way off. It has taken China and Singapore two decades to build world-class education systems, and policymakers in Russia need to take a longer-term view. There is also real scope, however, for rapid improvement in the short term. Currently, low levels of internationalization present a strategic opportunity for Russia. When cross-border cooperation, publishing, and benchmarking are stepped up significantly, as in the East Asian science systems, major gains can be achieved in Russia.

Keywords: higher education, international comparisons, university rankings, research, science policy, globalization.

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Introduction

Last year, the president of Russia announced that there should be five Russian universities in the global top 100 by the year 2020. Government funding has now been allocated toward the development of a selected group of 15 universities in order to achieve this goal [Vorotnikov, 2013]. Many other governments have similar objectives and programs.

This target of five universities in the global top 100 raises practical questions. Which global ranking system should be used to measure achievement of the top 100? How close is Russia to the target? Given the current standing of Russian universities in research according to all global rankings, is a time span of eight years (now seven years) feasible? And if the goal is to make Russia once again strong in science and technology, is this target the best way to drive the science system towards that goal and measure Russia's progress towards its achievement?

On the question of which ranking system ought to be used, the only rankings worth using when measuring performance and strategizing to improve are the research-based Shanghai Academic Ranking of World Universities [ARWU, 2014], or, even better, the Leiden University [2014] or Scimago [2014] measures of science publishing and citations. Both of these rankings use objective data from either Thomson-Reuters Web of Knowledge (Leiden University) or the similar, but not identical, Elsevier collection (Scimago), the two major collections of journal papers and citations. Both rankings represent these data as a single indicator.

The QS [2014] and the *Times Higher Education* [2014] rankings rely partially on reputational surveys; thus, few are convinced that such rankings are accurate. To base a university's ranking on opinion surveys is similar to asking a group of people to guess the distance between the earth and the sun and then using the average guess to determine the distance. Taking the average of many guesses would not be very responsible astrophysics, and it is not very responsible social science when applied to higher education. Further, individual universities can boost their positions in the QS and *Times Higher Education* rankings by negotiating with the companies on the interpretation of their data and by marketing themselves so that they may do better in the reputational surveys. But "success" of this kind is an illusion. It disappears as soon a new survey comes out or the marketing campaign dies down. What matters is measuring the real firepower of Russian science and technology, not managing impressions or promoting individual institutions. One of the reasons for the rapid growth of science in China is that the Chinese government focuses on genuine measures of scientific and technological performance, not measures that can be influenced by non-merit factors such as marketing and negotiation.

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The president's ambition is appropriate; Russia should expect a leading role in science and technology. Intellectual work in Russia has long been one of the small number of major and essential strands of world culture and science. Great traditions do not disappear, even though they may be eclipsed for a period of time, as was the case in

China from 1840 to 1950. Russia has made many seminal contributions to knowledge, technology, and understanding, and we can expect that it will make more such contributions in the future. These will benefit not only the Russian national economy and quality of life, but all of human society, and the president is right in wanting to want to bring that process forward. The important questions, then, are: What is Russia's current position? What are the best means of measuring it? How far must Russian science travel to achieve a major global role again? What is the best developmental strategy for building capacity and performance in Russian science and technology? What are the strategic imperatives in the present global system of science?

For it is essential to be realistic about the current position of Russian science and to understand as well as possible the global conditions in which it seeks to progress.

The impact of globalization

Much has changed since Soviet times, not only in Russia but also in the world at large. Since 1990, the development of internet-mediated communication has transformed science. Science had always been something of a global conversation, but it was organized primarily in national systems. We now have a global science and technology system that has partially subsumed national scientific conversations. There are pockets of secrecy in science and technology for strategic military and industrial reasons, but it is important to recognize that the vast bulk of *strategic* knowledge—powerful, useful knowledge—is out in the open and flows freely around the world.

Features of this world science system include the explosive growth of web-based global publishing in English, both in the form of major disciplinary journals and the open-access circulation of papers, ideas and data; the continuing growth in the number of scientifically active nations [Marginson, forthcoming]; the great increase in the number of publications with international co-authors [NSF, 2014]; the fact that two thirds of citations are international; and the central role now played by collaborative research grant programs such as the European Research Area. All these international aspects of science are no longer positioned on the edge of national science; they have become the main conversation in science. National science is now on the edge of the global system, and its effectiveness depends on its capacity to operate globally.

This point, which is crucial in conversations about research and science in Russia, cannot be emphasized too strongly. All national innovation systems are now also part of the global innovation system. *Most innovations in technology and product development are now sourced partially or entirely from global sources, not national sources.* Thus, it is essential to become very good at accessing global science, which means becoming very good at producing global science and collaborating with others. Everyone is borrowing freely from everyone else by accessing the common store of knowledge. Countries partly disengaged from the global science system (e. g., North Korea) are increasingly being penalized. They are falling behind. No single country, regardless of its size, can develop all important new knowledge on its own—not even the United States, which still produces almost half the top 1 per cent papers in science [NSF, 2014]; there are too many other sources of new ideas.

Because countries like North Korea do not work openly or collaborate freely, they do not receive full access to knowledge and cutting-edge expertise from abroad. As they do not contribute freely into the global system, their scientists lack profile and fail to build international relationships based on continuous exchange and collaboration, which would allow them to utilize new knowledge as it emerges. They do not draw strategic talent from other countries. North Korea's best scientists want to leave the country to work at the cutting edge somewhere else, as was the case in Russia in the 1990s. In this global environment, systems that facilitate the mobility of science and people, such as the American system, prosper. For example, China, Korea and Singapore now have come to understand this reality and have created broad highways between their systems and the systems of other countries.

Comparative research spending

Let's look now at patterns of investment in research and development (R&D) and patterns of research output around the world. Where is Russia positioned?

When it comes to research, you get what you pay for. It is true that money alone is not enough—nations that increase funding will not obtain the expected results if organizational systems and cultures are not right. In the long run, however, without stepping up resources it is difficult to increase the quantity and quality of scientific output, and without investing at high levels it is impossible to become a leading research nation. There is a close correlation between R&D investment (especially government investment in basic research) and the number of science papers published, the number of highly cited science papers, and the number of highly ranked research universities in any given country.

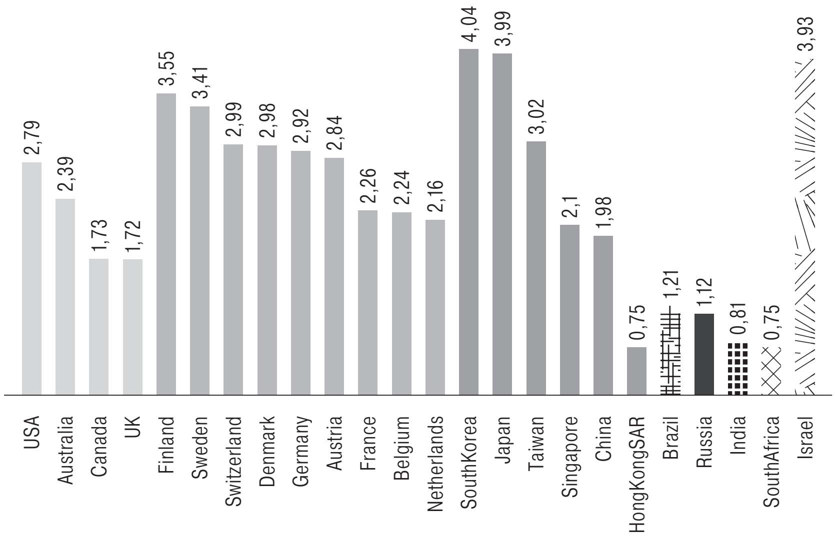
Russia's current investment in R&D is lower on the international scale than was Soviet R&D investment. Table 1 focuses on total R&D investment in the private and public sectors in the years 2000 and 2012 (or the nearest year). As expenditure is recorded in constant 2005 US dollars, it is clear which nations are rapidly increasing their funding. In 2010, Russia ranked tenth in total R&D investment. Though funding doubled between 2000 and 2012, it was from a low base. The 1990s were a desolate time in Russian science and set it back substantially. The level of R&D investment in Russia in 2012 was only 6.1 per cent of that of the United States, 11.4 per cent of that of

Table 1. **Expenditure in R&D in 2000 and 2012 (in constant 2005 USD) and proportion of GDP allocated to R&D in 2012 or nearest year, leading countries**

System	R&D spending as proportion of GDP 2012 %	Increase in R&D spending 2000–2012 %	Total R&D spending constant 2005 USD $s billion	
			2000	2012
United States	2.79	+31.2	302.8	397.3
China	1.98	+601.0	30.4	213.1
Japan	3.39	+21.1	110.0	133.2
Germany	2.92	+35.1	61.6	83.2
South Korea	4.04	+174.3	20.2	55.4
France	2.26	+20.0	36.9	44.3
UK	1.72	+14.5	31.1	35.6
India	0.81	+139.3	13.5	32.3
Brazil	1.21	+75.0	14.0	24.5
Russia	1.12	+84.8	13.2	24.4
Canada	1.73	+13.6	19.1	21.7
Taiwan	3.02	+117.2	9.9	21.5
Italy	1.27	+23.8	16.4	20.3
Australia	2.39	+104.5	8.9	18.2
Spain	1.30	+72.8	9.2	15.9
Netherlands	2.16	+26.9	10.4	13.2
Sweden	3.41	+4.6	10.8	11.3
Switzerland	2.99	n.a.	6.4	n.a.
Austria	2.84	+77.6	4.9	8.7
Israel	3.93	+45.0	6.0	8.7
Turkey	0.86	+183.3	3.0	8.5
Belgium	2.24	+32.8	6.1	8.1
Finland	3.55	+29.8	4.7	6.1
Singapore	2.10	+110.7	2.8	5.9
Denmark	2.98	+31.7	4.1	5.4

Data for 2011 not 2012: Japan, South Korea, India, Brazil, Turkey, Switzerland.
Data for 2010 not 2012: Australia, Taiwan (expenditure only).
Data for 2001 not 2000: Sweden, Denmark.
Source: [UNESCO, 2012; CIA Factbook, 2014; Taiwan Today, 2014] .

Figure 1. **Investment in R&D as a proportion of GDP, 2012 or nearest year, selected leading countries** (%)



Data for 2011: South Korea, Japan, Brazil, India, Switzerland.
Data for 2010: Australia, Hong Kopng SAR, South Africa, Taiwan
Source: [UNESCO, 2014] .

China, and less than half the level of South Korea, whose population is only one third as large as Russia's [UNESCO, 2014].

The table also provides data on the proportion of GDP allocated to R&D in 2012 (or the nearest year). These data are re-expressed in Figure 1, which clusters national systems by region. Russia's total investment in R&D of 1.12 per cent of GDP in 2012 was the lowest of the top ten R&D countries with the exception of India. Russia's investment in research was higher than that of two of the BRICS countries (India and South Africa) but below that of Brazil and China. However, it is probably more appropriate to compare Russia not to the BRICS countries, which are only now developing high-capacity systems, but to the English-speaking and Western European nations, which have a longer history of developed research.

The standout countries in R&D are the US, smaller, knowledge-intensive European countries in Scandinavia and Switzerland, and the rising science powers in East Asia and Singapore. China is increasing its investment in R&D by 0.1 per cent of GDP per annum, a rate at which it will surpass the United States' GDP share within a decade. At that stage, China's R&D budget will be much larger than that of the US. Korea, Taiwan and Singapore are smaller than China but also exhibit dynamic growth. It is apparent that in this century much of our new science and technology will come from East Asia. How much will come from Russia?

Comparative research outputs

Russia's comparative international position in globally published science—the science that enters the common store of human knowledge and is published in English, currently the only global language—is weaker than its comparative R&D investment. Russia was tenth in R&D investment in 2012 but 15th in the number of science papers produced in 2011—not far behind the Netherlands (in 13th place), which has 10 per cent of Russia's population, and Taiwan (in 14th place), which has 15 per cent of Russia's population. Russia's output of published science in 2011 was 6.6 per cent that of the United States and 15.8 per cent that of China. Surprisingly, output had fallen from 15,658 papers in 2001 to 14,151 in 2011, an average annual decline of 1.0 per cent. Along with Japan (1.7 per cent per year) and Sweden (0.6 per cent per year) Russia was one of only three countries in the top 20 research producers where output declined. The average annual growth in output on a worldwide basis was 2.8 per cent [NSF, 2014]. The decline of output in Russia can be attributed to the continued erosion and ageing of the Soviet research system, the slow emergence of comprehensive research universities, and the slow rate at which the whole system has internationalized.

Why is published science in Russia weaker than funded research? Much of the research in Russia takes place in academies and other institutes outside the university system as well as in specialized universities that service the manufacturing, energy, extraction, and defense sectors [Scimago, 2014]. There has been some growth in comprehensive research universities, but other research organizations still dominate. Many of the papers produced by specialized institutes and universities are exclusively in Russian and not available in English. The Soviet strategy was "science and technology in one country." Contacts between Soviet and foreign researchers were not encouraged. Useful research from abroad was translated into Russian and fed into the bounded national science system. Little research flowed out, primarily to avoid giving away strategic secrets and to keep researchers in Russia. The closed-door legacy of the Soviet period continues to retard Russia's global awareness and engagement. There continues to be localized research in support of engineering, manufacturing, aerospace, and defense industries conducted in specialized universities and institutes, but much (or perhaps most) of this scientific work is conducted and circulated in Russian and does not lead to worldwide exchange of knowledge. In short, Russian science and technology are less internationalized than those of all other nations ahead of Russia in the table. This point will be explored later in the article.

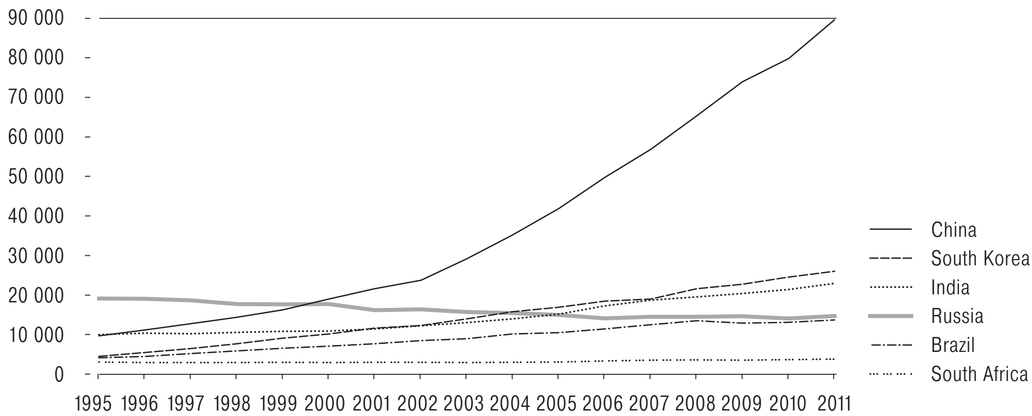
Figure 2 compares trends in output in Russia, China, India, Brazil and South Africa—the BRICS countries. In 2011, China published the second highest number of research papers after the US. China's published science in English grew by an amazing 15.6 per cent per year in the 1995–2011 period, despite the fact that its research sys-

Таблица 2. **Общее количество статей, опубликованных в ведущих научных журналах в области естественных и социальных наук в 2001 и 2011 гг., 30 стран-лидеров**

Страна	Science papers		Average annual growth 2001–11 %	Share of world total papers 2011 %
	2001	2011		
United States	190 597	212 394	1,1	25,7
China	21 134	89 894	15,6	10,9
Japan	56 082	47 106	−1,7	5,7
Germany	42 678	46 259	0,8	5,6
United Kingdom	45 588	46 035	0,1	5,6
France	30 602	31 685	0,3	3,8
Canada	21 945	29 114	2,9	3,5
Italy	22 093	26 503	1,8	3,2
South Korea	11 008	25 593	8,8	3,1
Spain	15 324	22 910	4,1	2,8
India	10 801	22 480	7,6	2,7
Australia	14 484	20 603	3,6	2,5
Netherlands	12 117	15 508	2,5	1,9
Taiwan	7 912	14 809	6,5	1,8
Russia	15 658	14 151	−1,0	1,7
Brazil	7 052	13 148	6,4	1,6
Switzerland	7 950	10 019	2,3	1,2
Sweden	10 022	9 473	–0,6	1,1
Turkey	4 151	8 328	7,2	1,0
Iran	1 035	8 176	23,0	1,0
Poland	5 629	7 564	3,0	0,9
Belgium	5 827	7 484	2,5	0,9
Israel	6 235	6 096	–0,2	0,7
Denmark	4 917	6 071	2,1	0,7
Austria	4 480	5 102	1,3	0,6
Finland	4 930	4 878	–0,1	0,6
Norway	3 215	4 777	4,0	0,6
Portugal	2 081	4 621	8,3	0,6
Singapore	2 434	4 543	6,4	0,5
Greece	3 204	4 534	3,5	0,5

Source: [NSF, 2014].

Figure 2. **Annual output of published science papers in the BRICS countries (Russia, China, India, Brazil, South Africa) and South Korea, 1995–2011**



Source: [NSF, 2014].

tem is more focused on applied and commercial R&D than basic science, and a large number of its people has managed to learn English in just one generation. China will become number one in the volume of published science in less than a decade, though it will remain well behind the US in citations per paper and in the weight of highly cited papers for some time to come. Comparing citation rates, China publishes more top 1 per cent papers than the US in just one field—computer science—but it is only halfway to the position of the US in chemistry and engineering. It is well behind North America and Europe/UK in biological sciences, medicine, social sciences, and psychology [NSF, 2014].

In 1995, China produced the same number of papers as India and was well behind Russia. China has now rocketed ahead of both countries. Among these three nations, Russia has fallen back from first to third place and is only slightly ahead of Brazil.

East Asian universities and research

It is useful to look more closely at East Asia. Though China does not yet have any Shanghai ARWU top 100 universities, the number of top 500 universities there has jumped from eight in 2005 to 28 in 2013, less than a decade later. The number of top 500 universities in Taiwan has risen from five to nine. Over the same time period, the number of Russian universities in the top 500—two—has not changed. Research rankings are usually slow to change, and it is hard to break into them from below.

Since 1990, China, Taiwan, South Korea, and Singapore have transformed their research and higher education systems. How has it happened, and could it happen in Russia, too? Some conditions and elements of East Asian systems and cultures can be replicated in Russia; some cannot. The most distinctive feature of East Asian educational culture is the traditional Confucian commitment to learning at home. This is at the core of parent-child relations; it is partially a responsibility of parents to their children and partially a duty of children to their parents. Some Russian families share this very deep commitment to learning and formal education, but not all. The Confucian tradition underpins all the extra schooling outside school, the private tutoring, the extra hours, and the dedication that characterizes secondary school students in East Asia. In Sinic tradition, it is believed that success comes not from talent but from hard work.

One consequence is that East Asian systems lead the world in the OECD's PISA ranking of achievement in reading, mathematics, and science. Only Finland can compete with the East Asian systems. As Table 3 shows, the first seven systems in 2012 PISA mathematics were all from East Asia and Singapore. These systems have large numbers of high achievers and a relatively small number of low achievers compared to the OECD average and to the United States and Russia [OECD, 2014]. This pattern of student achievement is a very strong platform on which to erect university education. It is interesting that even Vietnam, which is much weaker economically than its East Asian neighbors, outscores US and Russia in all three PISA disciplines.

The other two key elements that explain the success of China and the rest of East Asia and Singapore are effective states and accelerated internationalization. Governments in East Asian countries are more competent than those of most states. The quality of these countries' leaders is high—many top graduates choose government careers because of the respect that profession commands in Sinic tradition. Like in other regions of the world, government in East Asia is politicized, but on the whole, it is more meritocratic and performance-driven, and mostly less corrupt, than in the post-socialist countries. The East Asian states identify education and science as high priorities; they therefore focus substantial investment in these sectors and set performance targets that are authentic and not just words on paper. They monitor progress toward achievement of those targets, and then they raise the targets further to drive progress. The result is the real and rapid improvement that is taking place.

Over the last two decades, East Asian systems have lifted participation rates, restructured their systems, and created world-class universities (except for Japan, which did it in the 1970s and 1980s). Internationalization has been a key driver of improvements. Encouraged by the state, universities set incentives for English-language publication, bring back the diaspora from the US, attract foreign talent, support collaboration with foreign scholar-researchers, and engage in systematic benchmarking with strong foreign universities. A bench-

Table 3. **East Asia, Singapore and selected others in the OECD's Programme of International Student Assessment (PISA), 15-year olds, mathematics, 2012**

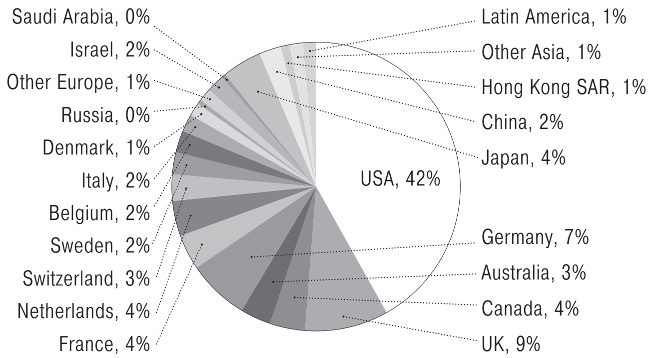
Страна	Position in PISA table for learning achievement of 15-year olds in mathematics (n= 65)	Mean score in PISA mathematics	Proportion of all students in the PISA groups	
			top (Levels 5–6)	bottom (Level 1)
OECD average	—	494	12,6	23,1
Shanghai, China	1	613	55,4	3,8
Singapore	2	573	40,0	8,3
Hong Kong China SAR	3	561	33,7	8,5
Taiwan	4	560	37,2	12,8
South Korea	5	554	30,9	9,1
Macao China SAR	6	538	24,3	10,8
Japan	7	536	23,7	11,1
Switzerland	9	531	21,4	12,4
Germany	16	514	17,5	17,7
Vietnam	17	511	13,3	14,2
United Kingdom	26	494	11,8	21,8
Russia	34	482	7,8	24,0
United States	36	481	8,8	25,8

Source: [OECD, 2014].

marking approach to international comparison is a more focused, contextually appropriate, detailed, and transformative strategy than a rankings approach [Altbach, Salmi, 2011]. East Asian governments see better rankings for their universities as the outcome of policy and of better performance, not as a principal policy instrument or driver.

To focus on ranking outcomes as the objective of policy is to focus on reputation and the *appearance* of global strength rather than focusing on real education, real science, and the *substance* of global strength. By the same token, it is essential to use only those rankings which are soundly based in social science and which have a virtuous relationship with actual performance [Marginson, 2014]. In other words, strategies to improve rankings tend to lift real capacity and quality in higher education, and improved higher education and research really leads to better rankings. That is not necessarily the case with QS and the *Times Higher* rankings.

Figure 3. **Shanghai Academic Ranking of World Universities top 200, 2013**



Source: [ARWU, 2014].

How strong is Moscow State University?

Returning to science and higher education in Russia, how well does the nation perform in science publication and citation, the most objective data available in rankings? The Shanghai Academic Ranking of World Universities is a solely research-based ranking. There is one Russian university in the Shanghai ARWU top 200: Lomonosov Moscow State University (LMSU), in 79th place. St Petersburg State University is in the 300–400 group. Moscow State's ARWU rank is partly a function of its past Nobel Prize winners, which does not explain much about current research performance. It is possible to obtain a clearer picture of the relative position of Moscow State and other Russian institutions by using the Leiden University and Scimago rankings.

The Leiden University ranking is very accessible; the website provides separate measures of each university's total science papers in global journals, citations per paper, and the proportion of all published papers in the top 10 per cent of their field of research, which is based on citation rates. Leiden looks at only the top 750 universities in the world by paper volume. The only Russian university in the list is Moscow State. It comes in 305th place in the world in terms of paper volume—it published 2,888 papers in the 2009–2012 period under analysis by Leiden, compared to 29,693 at Harvard, 9,149 at MIT, and 14,399 at the University of Tokyo, the top university from a non-English-speaking country—and 4.8 per cent of its papers were in the top 10 per cent of their field. Moscow State was 697th out of 750 universities on citation rate and published just 138 highly cited papers: 74 in natural sciences; 29 in life sciences; 15 in mathematics, computer science and engineering; 11 in earth and environmental sciences; 6 in medical sciences; and none in either cognitive sciences or behavioral sciences [Leiden University, 2014].

Table 4. **Number of science papers and high-citation papers in selected leading universities in eight countries, science outputs for 2009–2012**

University and system	Number of journal papers	Average field normalized citation rate (mean = 1.00)	High citation papers (top 10% of field)	
			Number	Proportion of all papers, %
U California Berkeley USA	11 384	1.90	2560	22.5
Massachusetts IT USA	9 149	2.05	2304	25.2
U Cambridge UK	11 778	1.55	2163	18.4
U College London UK	11 434	1.55	1833	16.0
Ludwig-Maximillians U Munich GERMANY	7 081	1.20	928	13.1
Technical U Munchen GERMANY	5 733	1.29	811	14.2
Tsinghua U CHINA	9 713	1.03	1025	10.6
Peking U CHINA	9 534	0.96	906	9.5
Indian IT Kharagpur INDIA	4 108	0.78	190	6.4
U Delhi INDIA	3 333	0.72	111	7.5
Lomonosov Moscow State U RUSSIA	2 888	0.61	138	4.8
U Sao Paulo BRAZIL	12 319	0.67	634	4.6
U Cape Town SOUTH AFRICA	2 333	1.06	257	11.0

Source: [Leiden University, 2014].

Tables 4 and 5 compare LMSU's research output in the global science system with selected individual leading universities outside Russia in more detail. Table 4 compares LMSU's overall research output with a group of leading universities in the United States, United Kingdom, Germany, China, Brazil, India, and South Africa that are comparable to LMSU. These individual universities are not necessarily the top one or two in their systems by paper volume or citation rate, but they have been chosen because they parallel LMSU as national universities, capital city universities, or science and technology leaders. In the other BRICS countries, there are more universities in the Leiden ranking than Russia's one. There are 16 in India (though with relatively low citation rates), 13 in Brazil, five in South Africa, and no less than 83 in China, which has the world's second largest research system.

Table 4 shows that at present, in terms of global science, Lomonosov Moscow State is not in the same league as the top universities in the English-speaking world and Germany and has been left well behind by the two universities in Beijing, China and Brazil's large University of Sao Paulo. Sao Paulo has a lower proportion of high-citation papers than LMSU (4.6 per cent compared to 4.8 per cent) but a better average citation rate. In aggregate terms, it produces many more papers and many more high-citation papers. Like LMSU, Sao Paulo has the disadvantage of being a major national leader operating in a global research setting, but it is clear from these data that Sao Paulo's faculty members more actively bilingual. The University of Cape Town in South Africa is much stronger than LMSU in citation quality. Note that in Table 4 Harvard has been left out of the comparative measures simply because it is so large and so strong in research that it dwarfs every other university on earth. To illustrate this point, Harvard produces more than *twice as many* top 10 per cent high citation papers (6,818) than the next university in the United States and the world, Stanford (2,993), thirty times as many high-citation papers as LMSU, and as many such papers as the entire Swiss university system (Switzerland has seven universities in the Leiden ranking and produces the highest quality research of any nation in continental Europe).

Table 5 compares LMSU's high-quality research papers by discipline with those of two other universities: Utrecht University in the Netherlands, the leading institution in a system that is very effective in sustaining global research quality in a non-English-speaking country, and the National University of Singapore (NUS), which is an outstanding example of an institution that has been deliberately and rapidly elevated to the status of a world-class university by a central nation-state. Nominally, NUS is the kind of university that Russia will have if the president's five-in-100 plan succeeds.

Peter the Great would likely have compared LMSU with a top Dutch institution. This is not a suitable comparison because the leading Russian university—and the only one in this ranking—is not fully engaged globally in the manner of Utrecht and NUS, and there is no way of taking into account LMSU research published in the Russian language. At Utrecht, the percentage of highly cited papers is greatest in earth and environmental science (18.6 per cent), mathematics, computer science, and engineering (17.5 per cent, even though Utrecht does not have a full engineering department), and natural sciences (16.6 per cent). At NUS, the strongest areas in terms of the number of highly cited papers are earth and environmental sciences (20.4 per cent) and natural sciences (16.0 per cent). At LMSU, there are no strong areas. The percentage of highly cited papers is greater in earth and environmental sciences (7.9 per cent, with an average citation rate of 0.77) than other areas. There are no high-citation papers in the English language literature in cognitive and social sciences. Despite Russia's historical strengths in mathematics and engineering, there were only 15 highly cited papers in those disciplines over the period of four years, and 4.7 per cent of all papers received high citations. The average citation rate was 0.63 [Leiden University, 2014].

Table 5. **Comparison between Lomonosov Moscow State University in Russia, University of Utrecht in the Netherlands, and National University of Singapore: high-citation (top 10 per cent) papers by research field, 2009–2012**

All data for 2009–2012 inclusive	University of Utrecht NETHERLANDS	National University of Singapore SINGAPORE	Lomonosov Moscow State University RUSSIA
Total journal papers	8545	10,387	2888
Total journal papers in top 10% of field by cites	1197	1361	138
Proportion of all papers in top 10% by cites	14.0	13.1	4.8
Field-normalized average cites per paper	1.41	0.93	0.61
Top 10% papers			
Cognitive Sciences	180	36	0
Earth and Environmental Sciences	121	103	11
Life Sciences	259	235	29
Math., Computer Sci., Engineering	39	221	15
Medical Sciences	336	130	6
Natural Sciences	162	559	74
Social Sciences	101	76	0

Source: [Leiden University, 2014] .

This comparison makes it clear that Russia is performing poorly. There is a wide gap between LMSU and a real top 100 university (the ARWU position is confirmed as misleading), and with no other Leiden-ranked top 750 university, it will be impossible for Russia to achieve five genuine top 100 universities in the near future. This should not be surprising. It has taken 15 years for China to build a strong research system driven by exceptional and continually increasing levels of investment, and even so, it does not yet have any top 100 universities except in terms of number of published papers. It has taken 25 years of exceptionally high investment and focused policy for the National University of Singapore—which at present is significantly stronger in research than any mainland Chinese university—to reach standards similar to those of a leading Northwestern European university. This suggests that if the five-in-100 by 2020 or 2030 is unachievable, it is better to adopt another target to drive improvements in research capacity and performance. More fundamentally, it suggests that a different approach to comparison, one that takes into account the specific historical context of Russian science, is needed. It is also necessary to identify the indigenous strengths of Russian science, rather than solely focusing on the weakness of Russian science in terms of global production and engagement, as such strengths are resources for the regeneration of research.

The Academy and research institutes

The history of Russian science in separated research institutes and specialist universities aligned to specific industries whose activities are not primarily focused on producing global knowledge has been discussed above. The continued traditional role of the Russian Academy of Sciences and non-university institutes retards the emergence of comprehensive Russian universities. It is not possible for the universities to develop in the manner of Anglo-American or Western European comprehensive universities if there is no change in the way the organizations that formerly dominated the science system are configured. There is no doubt that the partial or complete collapse of scientific institutions in the 1990s postponed the resolution of these structural issues [Smolentseva, 2014]. China had the same structural background but has systematically created a new system. China's experience suggests that it is possible to sustain an effective research system that includes both academy/institute structures and teaching/research universities, with both the universities and the other research organizations evolving into new kinds of organizations with higher levels of internationalization and productivity. A key aspect of China's success has been its focus on publishing in English.

The Scopus data collection Scimago, unlike the Leiden ranking, allows the output of non-university research organizations to be explored. There are more papers in the Scimago collection than in the Leiden collection because there is greater inclusion of formats other than research articles in the former. Table 6 shows that China strongly outperforms both the Russian Academy and the Russian universities. For an institute in a non-English-speaking country, China's Academy of Science, which is the second-largest research organization in the world in terms of the volume of research it produces, has a good academic impact factor (normalized across academic fields) of 1.01. Tsinghua University is at 0.96. The Russian Academy is the third-largest research organization in the world, but the average impact for papers published in English is only 0.54 and below LMSU at a low 0.63 [Scimago, 2014].

The Scimago collection, which for 2013–2014 includes 2,744 university and non-university research organizations ranked in order of volume of papers—many more than the 500 in ARWU and the 750 in Leiden—allows two other questions to be explored. First, aside from LMSU, which are the best-performing Russian universities? The answer to this question may give us an idea of where the five Russian universities in the world top 100 might (eventually) come from. Second, the non-university research organizations may have world-class research strengths that could be brought into the universities through mergers (though the difficulties of achieving successful mergers

Table 6. **Output of science papers from national academies and leading universities, 2007–2011, China and Russia compared**

World rank on volume	Research organization	Total volume of papers 2007–2011	Normalized impact (average = 1.00, Harvard U = 2.40)
2	Chinese Academy of Sciences CHINA	157,814	1.01
11	Tsinghua U CHINA	48,396	0.96
19	Zhejiang U CHINA	42,606	0.87
24	Shanghi Jiao Tong U CHINA	39,399	0.81
3	Russian Academy of Sciences RUSSIA	97,105	0.54
115	Lomonosov Moscow State U RUSSIA	20,151	0.63
624	Russian Academy of Medical Sciences RUSSIA	5694	0.63
660	St Petersburg State U RUSSIA	5404	0.61

Source: [Scimago, 2014].

should be acknowledged). Which research organizations have the highest research quality as measured by the Scimago Impact factor? Table 7 addresses these two questions. It lists the first eight Russian universities in terms of paper volume and the first 12 Russian research organizations in terms of the normalized impact factor. (The listed institutions in Table 7 have not been compared with the list of institutions selected to receive developmental funding in the government's five-in-100 program; it is not the intention of this paper to enter a discussion about the wisdom or otherwise of that selection).

The current top eight in terms of paper volume includes LMSU, St. Petersburg State University, Novosibirsk State University, three federal universities, and the Moscow Engineering Physics Institute. Those below MSU and St. Petersburg State are currently ranked between 1,207 and 1,698, which in volume terms is not anywhere close to the world top 100. This table confirms that Russia has a long way to go before meetings its target. The list of high-impact research organizations—none are comprehensive universities—indicates the continuing Russian global research strength in physics and its applications including nuclear science, energy, space, and engineering. The Institute for High Energy Physics is in the world's top 80 highest-impact organizations as measured by the normalized impact indicator. The table also shows that the Academy of Sciences retains pockets of research excellence. The new knowledge generated in these organizations mostly falls outside the global university research rankings. If the specific institutes and the branches of the Academy were fully affiliated with individual universities—which could be done without depriving the institutes of their autonomy—it would be a different matter.

Table 7. **Leading research universities by volume and leading research organizations by normalized impact (NI), Russia, 2007–2011**

World rank on volume		Total volume of papers 2007–2011	Normalized impact NI (average = 1.00, Harvard U = 2.40)
UNIVERSITY			
115	Lomonosov Moscow State U	20,151	0.63
660	St. Petersburg State U	5404	0.61
1207	Novosibirsk State U	2609	0.58
1509	Ural Federal U	1872	0.51
1567	Moscow Engineering Physics Institute	1771	1.11
1592	Southern Federal U	1726	0.36
1698	Moscow Institute of Physics & Technology	1547	0.60
1698	Kazan Federal U	1547	0.45
RESEARCH ORGANIZATION			
	Institute for High Energy Physics	1215	2.65
	Institute for Nuclear Research, Acad. of Science	1029	1.85
	Kostantinov Petersburg Nuclear Research Instit.	1896	1.84
	Alikhanov I. Theoretical & Experimental Physics	2435	1.84
	Budker Instit. Nuclear Physics, Acad. of Science	1438	1.43
	Joint Institute for Nuclear Research	5072	1.28
	Landau I. for Theoretic. Physics, Acad. of Science	769	1.13
	Moscow Engineering Physics Institute	1771	1.11
	P N Lebedev Physics Institute Acad. Of Science	3486	1.06
	Russian Research Centre Kurchatov Institute	2674	0.83
	A. M. Prokhorov Gen. Physics I. Acad. of Science	2047	0.79
	Space Research Institute Acad. of Science	1159	0.76

Source: [Scimago, 2014].

Elements of a strategy

How, then, can the global capacity of Russian science and technology be lifted? The current capacity of Russian science is a good base for development, providing that:

1. Existing capacity is reinforced and protected against further erosion, and there are adequate numbers of new researchers coming in given the large-scale turnover of Soviet-educated researchers that is likely to occur during the next decade;

2. Investment in R&D is increased to a globally competitive level of at least 2 per cent of GDP and is tightly targeted towards both existing areas of quality, on the and selected locations where capacity needs to be built up;
3. The innovation system is internationalized.

It is better to use targets that encourage all national systems to succeed and all universities to contribute to the national effort, not just a favoured few—for example, targets based on publication numbers and citation rates. Top 100 lists undermine overall national performance while promoting it at the same time; the success is limited, but the anxiety becomes universal. However, performance in the Leiden or Scimago indicators means something, and all institutions can improve their position on the basis of those measures. This also allows non-university research to be considered towards the achievement of national goals.

There are two caveats. First, it is important to remember that investment in R&D does not generate rapid gains and it must be sustained over decades. There are lags between investment in capacity, the growth of science output, the increase in citations, the counting of those citations for comparison purposes, and growth in the number of world-class universities. Not much can be expected by 2020, even if investment is stepped up above currently planned levels. Eight years is too short of a time horizon. China's experience suggests that it takes 10–15 years for major gains to become apparent; at non-Chinese levels of funding, it could take 20–25 years. The full benefits take at least a generation. As Jamil Salmi, the former tertiary education coordinator for the World Bank, often remarks when talking about world-class universities, "It is a marathon, not a sprint."

Second, global research quality is not the only issue. National needs are also significant, and policies to pursue national research objectives are not always identical to policies designed to increase global research capacity. It is necessary to pursue a tandem policy that encompasses the two sets of objectives and for researchers to be fluent and active in both global and national languages.

Internationalization is the key

Internationalization is the key to the next phase for Russian science and higher education. This is suggested by the fact that Russia's national research capacity is considerably greater than its global research performance, and the fact that Russia performs badly (comparatively speaking) in all internationalization indicators. There is much scope for improvement. More positively, the East Asian countries have shown what can be achieved via systematic internationalization strategies, including active partnerships, joint authorship, student and faculty mobility, rigorous benchmarking at the institution

Table 8. **Number of internationally co-authored journal papers, selected countries, 1995 and 2010**

Country	1995	2012	multiplication 1995–2012 1995=1.00
Singapore	359	4359	12.14
China	2914	31,081	10.67
South Korea	1283	10,079	7.86
Germany	14,694	39,161	2.67
Finland	1762	4717	2.68
United States	36,361	91,183	2.51
Russia	5509	7413	1.35
WORLD	79,128	211,841	2.68

Source: [NSF, 2014].

and discipline level, a concerted improvement of bilingual skills, and the provision of incentives to publish in English.

Language ability is the key to international research collaboration, which is where much of world science is moving. Between 1995 and 2012, the total number of journal articles with international co-authors rose by 168 per cent, much faster than journal articles as a whole, which rose by 47 per cent—another sign of the growing weight of the globalization of knowledge in the single world science system. In East Asia, joint publishing grew by anywhere from 8–12 times, depending on the country, as Table 8 shows. In Russia, the number of jointly published articles rose by just one-third. It is another sign of the remarkable lack of global engagement that characterizes intellectual life in Russia. Despite the opening up of Russian society in the late 1980s at the end of the Soviet period and the twenty years of relatively open international travel and communications since 1992, the science system remains surprisingly closed.

However, the closed nature of the system is not just a problem, it is also an opportunity. At the bottom of a curve, the only way is up. Because international collaboration, joint publishing, and total publishing are weak, they are domains in which Russia can make great gains in the coming years—and if there is an upsurge in international cooperation in these areas, many other things will start to change.

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