Russia: Nanotechnology Country Profile

Project on Emerging Technologies, Trajectories and Implications of Next Generation Innovation Systems Development in China and Russia

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The project on **Emerging Technologies and Implications of Next Generation Innovation Systems Development** in China and Russia addresses research, management and policy issues related to advanced technological development in driving the growth of Rising Powers economies. The project focuses on nanotechnology and other emerging technologies in China and Russia and is examining associated issues of institutional development, governance and global impact. The project is directed by Philip Shapira and Ian Miles (both at the University of Manchester) and by Alan Harding (University of Liverpool).

See http://www.risingpowers.net/projects/innovationsystems/ for further information about the project, including other outputs

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1 Summary

The Russian Federation is continuing with programmes to renew its national innovation system and to implement its nanotechnology development policy. The state continues as the main driver for innovation, and it is also the most important intermediary between scientific organisations and private sector companies. The government-controlled Joint Stock Company RUSNANO occupies most of the space in nanotechnology commercialisation, both by the amount of the investment and by the variety of activities. The federal government sets science priorities through government programmes and by allocating funds in prioritised orders annually, and pushes innovation through state-owned companies and corporations. The resulting system is a hybrid between a planned science and technology system and a more decentralised system of innovation.

There are many risks associated with the development of the nanotechnology science and innovation system in Russia. One of them is a great reliance on changing agendas; others include high centralisation, limited public engagement, weaknesses in the development and enforcement of standards and regulation, the underdevelopment of markets and the lack of internal demand for nanotechnology processes and products. Additionally, limited attention is paid to possible environmental and health and safety risks associated with nanotechnology.

Stakeholders involved in the innovation process of nanotechnology in Russia have to rely heavily on favourable political will to continue the state funding of nanotechnology. There is a high level of uncertainty and instability in nanotechnology and related markets, notwithstanding continuous investment in science and efforts to undertake large-scale innovation capacity building projects.

2 Innovation System Overview

2.1 Brief History

The Soviet state-planned Science and Technology (S&T) system was inspired by Marxist philosophical thinking throughout the 19th and early 20th century and was laid out in 1920s and 1930s as a part of broader ideas of state planning in government and industrial management. The Soviet S&T system has remained a benchmark for other state planning S&T systems until the present day (see Klochikhin, 2013).

The mature Soviet S&T system (Table 1) was a structure where basic research was performed in the Soviet Academy of Sciences; specialised applied research was performed in branch and industrial sectors. Branch sectors encompassed research institutes, design bureaus, engineering research institutes and experimental facilities belonging to branch ministries, including those oriented towards defence. The industrial sector of Soviet science mainly consisted of engineering departments within industrial enterprises. The main function of universities was to serve as higher education institutions (HEIs) performing teaching functions. At its peak, the system was largely skewed towards the military research (70-75% by the estimates of Gokhberg, 2003; 80-85% by the estimates of Dezhina, 2011).

Table 1 Mature Soviet Science, 01.01.1991 (from Science of the USSR in figures, 1990)

Indicators	Total	Sectors of science			
		Academic	Higher education	Branch sectors	Industrial sectors
Number of organizations performing R&D, units	7,974	1,276	877	5,103	718
R&D expenditure, %	100%	12.6%	6.8%	75.8%	4.8%
High-skilled R&D personnel with higher education, including:	1,659,000	164,000 (9.9%)	300,000 (18.1%)	1,095,000 (66.0%)	100,000 (6.0%)
PhDs	37,700	10,895	16,249	10,443	113
Candidate PhDs	298,000	53,640	128,438	112,942	2,980

The major defining features of the Soviet S&T system were a science-oriented innovation cycle and a linear view on innovation (termed 'implementation' during the Soviet period). Vaschenko (2010) points out that it was not the scientific discovery that would find an application, but the entire mechanism 'to implement' the discovery would be designed and constructed after the discovery had been made. Soviet S&T policies were oriented towards stimulating research, but not innovation (Gokhberg, 2003). Fundamental science and innovation were separated from production organisationally and by the number of institutional barriers. A universal pattern of 'implementation' was utilized without regard to sectoral and regional differences in the innovation process (Radosevic, 1999).

After the breakup of the Soviet Union in 1991, the science system underwent demilitarisation. With the decline of military orders came a fall in funding (Gorodnikova, 2008). There was a significant decrease in the military share of national R&D from 43% in 1991 to 26% in 1994 (Gokhberg, 2003). The lack of funding and declining salaries made pursuit of a scientific career less attractive. Both external and internal brain drain tendencies emerged (Gokhberg et al., 2010; OECD, 2011; Terekhov 2011). In the post-Soviet transition, efforts to promote the recovery of science and technology have had to deal with the lasting effects of the prior system. The structural organization of the system has been modified; however, some path-dependencies are still evident (Table 2). The major changes in the Russian research system after 1991 include:

- Relative growth of the share of academic sector (the state academies of sciences);
- De-emphasis of the higher education sector in terms of R&D;
- Emergence of a small group of private research organizations.

In particular, a new system infrastructure for innovation in Russia has had to be constructed. While the understanding of the innovation cycle has been rediscovered, there remains a void among intermediaries and non-governmental organisations (NGOs). Dezhina (2011) notes that major post-Soviet Science system reforms have occurred in in major leaps through 'Big Science' projects. The innovation policy 'leap' came in the early 2000s when first policies were formulated, and the word itself entered into public discourse in Russia. Innovation infrastructure (such as technoparks, regional innovation centres, educational-research and innovation complexes, innovation-industrial complexes and others) emerged and quickly diffused across the country. The second big 'leap' came in 2007 with the adoption of the National Nanotechnology Initiative (NNI) and the foundation of RUSNANO as a large state-owned innovation intermediary with broadly defined targets and priorities.

Table 2 Characteristics of Russian Science, 2011 (from HSE, 2013)

Indicators	**Total**	**Sectors of science[1]**			
		Government	**Higher education**	**Business enterprise**	**Private non-profit**
Number of organizations performing R&D, units	4,059	1,193	511	2,345	10
R&D expenditure, %	100%	29.8%	9%	61%	0.2%
High-skilled R&D personnel with higher education,	50,6330	176,984 (34.9%)	52,965 (10.4%)	27,5431 (54.4%)	950 (0.1%)

[1] Note: The government sector government agencies and non-profit organizations owned by the state. Higher education includes universities and other HEIs. The business enterprise sector includes organizations and enterprises which produce and sell goods and services including state-owned and private non-profit organizations providing services for enterprises. Private non-profit organisations include associations and professional organisations.

including:					
PhDs	27,675	17,789	5,774	4,018	94
Candidate PhDs	81,818	43,816	18,728	19,027	247

2.2 Institutional Structure of Russian National Innovation System

The Russian state is the main driver for R&D and innovation, and is also the most important intermediary between scientific organisations and private sector companies. The federal government sets science priorities through targeted programmes and by allocating funds in a prioritised order annually, and pushes innovation through state-owned companies and corporations. Kuznetsova (2007) illustrates this with statistical indicators: in 2007, 70% of Russian R&D organisations were publicly owned, while only 1% operated as private non-profit organisations. Government agencies provided over 50% of all funding for science. The state still dominates the STI system in terms of funding, the number of organisations, and the personnel employed in R&D activities (Table 3). The dominance of public and quasi-public structures at the centre of Russian innovation system means that privately-owned and not-for-profit research organisations are pushed to the periphery and have to rely on large public intermediaries for support of their operations.

Table 3 The Role of the Russian State in R&D, 2007 (from Kuznetsova, 2008)

Funding	Organisations	Personnel
Federal Budget Allocation (FBA) on civil R&D is 2.25% of federal budget expenditure FBA on civil R&D is 0.37% of GDP Government contribution as a source of R&D funding is 61.9%	73% of R&D organisations are owned or established by federal or regional governments Share of gross domestic expenditure on research and development (GERD) by publicly-owned R&D organisations is 74.5%	78% of R&D personnel work in government organisations (federal and regional) 86% of R&D fixed assets are public

2.2.1 Public Structures

The public sector sets the agenda and priorities in innovation policy. It has a range of instruments to promote the fulfilment of its decisions and obligations. The major public actors in Russian innovation system are:

- The President of Russia;
- Presidential Councils (Presidential Council for Economic Modernisation and Innovative Development, Presidential Economic Council, Presidential Council for Science and Education);
- The Ministry of Education and Science;
- The Ministry of Economic Development – within which is the Federal Service for Intellectual Property (Rospatent);
- The Ministry of Industry and Trade;
- Regional Governments.

A list of the main S&T functions performed by these public bodies can be found in Appendix 1.

2.2.2 Quasi-Public Structures

There are a number of quasi-government organisations that are not strictly public bodies, but are inseparable from the state. These are state-owned corporations, the Russian Academy of Sciences, All Russian Science Centres (including Public Research Centres), and State Universities.

State-owned corporations are important actors in the innovation system, as they constitute a large share of the economy. In recent years the government has been implementing a 'compulsion for innovation' policy for the large state-owned enterprises. The policy obliges each state-owned company to spend a share of its profits on innovative activities. The programme has had limited success so far due to previously unforeseen barriers (Gershman, 2013).

The Russian Academy of Sciences (RAS) is a federal budgetary institution (after the reform in 2013) funded by the state. RAS oversees three regional branches and regional scientific centres and is the primary research organisation in the country, carrying out research in natural sciences, social sciences, as well as in arts and humanities. After a reform in 2013, management of the property of RAS was handed over to the Federal Agency of Scientific Organisations (FANO).

All Russian Science Centres (branch institutes) are research institutions that were doing cutting-edge research during the Soviet time. Each 'branch' institute has a research focus (for example, the Kurchatov Institute primarily does nuclear research). Part of the research conducted in these institutes is still classified.

Public research centres (PRCs) are branch institutes with high R&D potential. In 2014 the list of PRCs included 48 Public Research Institutes and Universities. Many of the PRCs are established in the form of Federal State Unitary Enterprises (FSUE). These are organisations that operate using public assets and are obliged to give all profits to the state; however they operate on commercial accounts and under commercial legislation.

State Universities still do not play as major part in the innovation system, but are objects of active policy to stimulate commercialisation. The government adopted policy measures to stimulate research and innovation in leading national universities in 2008 and 2009: several Federal Universities were established, and 29 National Research Universities were set up. Research universities are awarded privileged funding, as well as other forms of support.

2.2.3 Funding of Science and Innovation

The funding bodies are clearly split into those that fund scientific organisations, such as the Russian Foundation of Basic Research (RFBR) and the institution of Federal Targeted Programmes and Government Programmes (FTPs), and those that fund industrial innovation.

Science funding is carried out by the following organisations:

- Russian Foundation for Basic Research (RFBR)

- Russian Science Foundation (RSF, since 2013)

Federal Targeted Programmes have been a core instrument of science funding since the era of the Soviet Union. These are set to reach pre-determined science targets with allocated fixed funds and fixed research teams (institutions and individual researchers) for a period of four years. Much criticism has been raised about this instrument due to it inflexibility and the lack of transparency (Kuznetsova, 2007). In January 2014, the President tasked the government with designing a new way to fund basic research and to move away from what was viewed as the obsolete FTP mechanism (President of Russia, 2014).

Another public funding instrument, 'government programmes', was developed recently. These programmes include all public funding instruments within a particular economic sector or priority. The Government Programme 'Development of Science and Technology in 2013-2020' systematizes all major federal budget funded activities within the S&T area, including specific FTPs.

Innovation funding is also state-dominated, although some private foundations are also involved. Public bodies established specifically to fund innovation are:

- The Russian Venture Company - set to operate with venture capital, and to attract investment from abroad. It is now a key venture capital organization that brings together public and private capital for start-up funding.
- The Russian Foundation for Technological Development – provides low-interest loans for R&D projects that involve small and medium enterprises aiming at the development of high-tech innovative production.
- Vnesheconombank (The Bank for Development and Foreign Economic Affairs) is a state corporation established to develop and diversify the Russian economy and serve as an agent of the innovation process.
- The Foundation for Assistance to Small Innovative Enterprises (FASIE) – provides research grants to individual inventors and small innovative companies.
- Skolkovo Foundation (part of Skolkovo Innovation Centre) assists start-up and research-intensive enterprises (see section 2.2.4).
- RUSNANO JSC (Joint Stock Company) acts as a venture capital company and funds domestic and international large-scale manufacturing projects. After the reorganisation from a state corporation to a JSC, RUSNANO has priority funding themes that include not only nanotechnology, but also energy, electronics, telecommunication, biotechnology and other areas.

2.2.4 Innovation Infrastructure

The innovation centre of Skolkovo (established by the Federal Law №244 on 28.09.2010) is the latest of Russia's 'Big Projects'. Skolkovo is an attempt to set up a Silicon Valley-like innovation hub in the vicinity of Moscow. It enjoys privileged economic conditions and tax breaks. Work on projects has begun before the physical construction of the centre is complete (due in 2015) after enterprises started registering online. A new Technical University in collaboration with MIT was founded. The Skolkovo Business School was set up to develop human resources to support the cluster. The project plays an important part of the Russian

Government's plan to attract leading foreign scientists and members of Russian scientific diaspora abroad, as well as to attract multi-national companies and other international players.

Tender bidding and contracting procedures have now become an element of Russian scientific practice following their inclusion in included in Federal Target Programmes. The establishment of tenders was new and has faced institutional challenges. In the first couple of years, the tender procedure was a significant hurdle to getting science funding due to gaps in legislation and mutual misunderstanding of the rules of the game (Tretyakov, 2009). RUSNANO commercialisation reports mention that in the first several years of functioning a significant number of 'good ideas' had to be rejected, because they did not fit the tender conditions or rules.

The new Federal Law of 5 April 2013 entitled "On the contract system of procurement of goods and services for public and municipal needs" provides specific instruments for the procurement of high technology and innovative products. However, its effects remain unclear for the moment.

Intellectual Property Rights are only weakly protected in Russia. An author idea is an object of legal protection, and there is no specialised funding for patenting ideas abroad allocated to researchers (Tret'yakov and Gudilin, 2009).

Technology Platforms are the most recent government initiative to bring together scientific research and industry funding to facilitate cooperation and innovation. They are designed as 'communication areas' to bring stakeholders together around a topic in one of the prioritised areas of development (such as biotechnology, nanotechnology, energy and others).

Dezhina (2011) estimates the efficiency of the innovation infrastructure that was set up since 2005 as 10-40%. Despite generous public spending on innovation, it is often hard to track how the money is spent and what are the outcomes of innovation initiatives.

2.3 Key Public Policies and Legislation

The Presidential Decrees of 7 May 2012 and the Government Programme 'Development of Science and Technology in 2013-2020' set major goals for Russian science, technology and innovation (STI) policy. A key goal is to systematize all major federal budget funded activities within the S&T area.

Planning continues to be formalised in the Russian S&T system. The 'Conception for Long-Term Development until 2020' (adopted 2008) outlines the long-term priorities of social and economic development and sets as a target of shifting Russia from a resource-dependent economy to innovation-oriented and socially responsibly forms of development. This is an overarching framework-setting policy document. 'Innovative Russia 2020' (adopted 2010) is a document that outlines the strategy of innovation development of Russia. It is based on the principles set in the Conception of the Long-Term Development and sets goals, targets and instruments of the innovation policy. A recent strategic planning document is 'Foresight of S&T Development Towards 2030' (adopted in early 2014).

This defines and prioritises areas of science and technology development in the long-term period.

A list of major programmes, FTPs and other relevant legislative and executive documents can be found in the Appendix 2.

2.4 Regional Issues

The Russian government has implemented policies to foster regional diversification of the science, technology and innovation system. There are a number of regional innovation infrastructure projects. These inclide innovation centres and innovation clusters, technoparks, and special economic zones. All these initiatives use the tax breaks and low interest bank loans to stimulate economic growth and entrepreneurship. RAS regional institutes and 'science cities' (naukograds), such as in Tomsk and Novosibirsk, further seek to decentralise Russian scientific activity.

The most recent initiative of the Ministry of Economic Development is a network of the Regional Innovative Clusters launched at the end of 2011. The first round of the tender competition was completed in 2012. Twenty-five clusters, situated in high R&D concentration areas and characterized by a high level of competitiveness and high growth rates, were selected to receive federal support from the Ministry of Economic Development. All clusters selected had already demonstrated relatively high levels of performance in the past. There are also regional Innovation Cluster initiatives, such as the ones established by the Government of Moscow.

Regional policies that are initiated and adopted at the Federal level are not necessarily embedded into local regions. In the regions, the process of setting up of innovation clusters is often random, and infrastructure has to be created from scratch. Kordonsky (2008) notes that this impedes development as municipal public bodies are excluded from regional innovation decisions, and this generates disincentives for cooperation with the scientific cities and technoparks situated in their regions.

3 Nanotechnology Policy Overview

3.1 Key Policies/Legislation

This section overviews the development of key Federal policies in Russia related to nanotechnology. One can observe the increasing importance accorded to nanotechnology-related research in 2000-2006, with efforts to facilitate commercialisation starting in 2007. A plateau was reached after main nanotechnology funding programmes were finished in 2012. The milestones are the following (Tretyakov, 2007; Klochikhin, 2011; Gokhberg et al., 2012):

2000 – the Government adopted a programme for *Military Nanoelectronics of the Armed Forces of Russian Federation until 2010*. The programme aimed at the development of competitive R&D in technologies for electronics at the nanoscale. Some authors (Dementiev, 2008) note that this programme places Russia on a par with the United States as one of the early-comers in prioritising nanotechnology development.

2004 – The Russian Government adopted the *Concept of Nanotechnology Development until 2010*. This executive document is the first significant milestone in prioritising 'civil nanotechnology'. This processed reached a high point in 2007 when the President included civilian nanotechnology development as a strategic development goal for Russia in his Annual Message to the Federal Assembly. This was later reformed into Russia's National Nanotechnology Initiative (NNI).

The Government Resolution No. 540 (12.10.2004) revised the Federal Target Science and Technology Programme *Research and Development in the Priority Trends in Science and Technology for 2002-2006.* This added "The industry of Nanosystems and Materials" as a priority theme, allocating the $70 million to fund it in 2005, and $80 million in 2006.

July 2006 – the Government approved the FTP *Research and Development in the Priority Trends of Russia's Science and Technology Complex for 2007-2012*. Nanotechnology was included into the list of national S&T priorities for 2007-2012. There was a significant increase in the state funding of nanoscience to $5 billion.

April 2007 – the adoption of the Russian NNI *Strategy of Nanoindustry Development*. This sought "to direct financial and organisational resources at interdisciplinary research in nanotechnology-related areas and to create a competitive domestic market of nanotechnology-enabled products." The strategy targeted both the research and the commercialisation of nanotechnology. It is the central policy-formation document which established RUSNANO. The strategy sets three main tasks of the development of Russian nanoindustry:

1. To radically increase manufacturing of existing nanotechnology production;
2. To develop and commercialise new kinds of nanotechnology production;
3. To advance the development of new directions in nanotechnologies that provide for the establishment of a pan-industry research and manufacturing environment in Russia.

May 2008 – adoption of the *Programme of the Development of Nanoindustry in Russia until 2015*. The goal was to form a Russian nanotechnology industry sector that would be able to compete with other developed countries so as to foster technological and economic security, the defensive capability of Russia, and the quality of life of its citizens. The total national R&D expenditure equalled $26.6 billion, and another $16.4 billion was channelled into RUSNANO. The Programme was the last large-scale priority-setting document regarding nanotechnology development.

3.2 Regional Issues

Key legislation related to nanotechnology development has been adopted at the Federal level, as well as more general innovation legislation. There is no evidence of specific regional nanotechnology programmes or priorities, except for the extensive RUSNANO involvement as a part of its programme to foster regional infrastructure development. Some of the regional innovative clusters set up recently with the support of the Ministry of Economic Development contain a nanotechnology component.

4 Nanoscience

4.1 Institutions and key organisations

By 2011, the number of organizations engaged in nanotechnology R&D in Russia had grown to 485 (Gokhberg, 2012). In terms of nanotechnology R&D spending the higher education sector reached 36.3% while the government and business enterprise sectors comprised 36.7% and 26.4% respectfully (HSE, 2013). Universities, PRCs and the Russian Academy of Sciences are the major institutions that determine the development of nanotechnology research. Private research centres and industry research occupy minor parts of Russian nanoscience.

Although R&D in the tertiary education sector of the Soviet Union has been legitimate since the 1930s, most of Russian universities have remained as teaching bodies except for Federal Universities and National Research Universities that have developed capabilities to do nanoscience research.

Universities adopt different strategies to enhance their existing research capabilities. Some universities, such as Moscow State University (MSU), rely on close links with the RAS: many professors there have double affiliations. Others, such as the Moscow Institute of Physics and Technology (MFTI), engage actively in government funding projects to collaborate with the leading scientists abroad. The mega-grants programme provided new funding to open clean rooms and laboratories. It is suggested that nanoscience and nanotechnology have been buzzwords to win state grants (Mitchell, 2007).

All Russian Research Centres also rely on the government agenda and priorities. Some of the Research Centres managed to stay at the forefront of science, due to the personalities of their directors, prolonged scientific excellence, defence-based research, or political links. The research centre that probably benefited the most during the time when nanotechnology was prioritized was the All Russian Research Centre Kurchatov Institute, which is a scientific coordinator of the National Nanotechnology Initiative (NNI). The Head of the Institute, M. Kovalchuk, is reported to have lobbied the NNI (Nature 2009a). In recent years the original Nuclear Institute has been diversifying its activities to include nanotechnology-related disciplines, and has been receiving increased funding. In 2008-2009 the Institute received over $2 billion worth of state-of-the-art equipment for nano-engineering (Nature 2009b).

The Russian Academy of Sciences has a major presence in Russian nanotechnology research. Among all Russian institutions, RAS produced the greatest number of papers in nanoscience in the post-Soviet period (Terekhov, 2012). Among institutes of RAS, the Ioffe Institute of Physics and Technology is the most productive organisation (Karaulova et al., 2014).

Several steps were made to prioritise nanoscience within the Academy: RAS established a Scientific Council for Nanomaterials by the Presidium RAS (2002), RAS

Institute of Nanotechnologies and Microelectronics (2006), and a RAS Commission on Nanotechnologies (2007), the latter with a Nobel Prize winner Zhores Alferov as its chairman. Also, diverging from its customary rules, RAS appointed Kovalchuk, who is not a full member, as acting vice-president for nanotechnology so as not to be bypassed by nanotechnology funding (Nature, 2007).

4.2 Funding Nanoscience

Public funding is extremely important in nanotechnology research. The majority of funds in Russia's NNI are allocated for commercialisation. Hence, basic nanoscience is funded in a conventional way through government programmes, mainly FTPs, and research grants from RFBR. The main funding sources are:

- The Government programme 'Development of Science and Technology in 2013-2020' (coordinated by the Ministry of Education and Science)
- The Russian Foundation for Basic Research (RFBR)
- The Foundation for Assistance to Small Innovative Enterprises (FASIE)
- The Russian Science Foundation (newly established body)
- The Ministry of Defence, Russian Federal Space Agency, the Ministry of Industry and Trade, State Corporation 'Rosatom' have their own research programmes.

According to the NNI, RUSNANO is not allowed to spend funds on basic research on nanosystems that are outside large industrial projects. Funding from RUSNANO is focused on projects with explicit commercial prospects.

4.3 Nanoscience Infrastructure

A special FTP was set up in 2008 to develop the infrastructure of nanoindustry (FTP 'Development of nanoindustry infrastructure in the Russian Federation for 2008-2011'). Overall, about 15 billion Roubles were spent on the procurement of equipment, construction works and modernization of research labs; and about 10 billion Roubles on specific equipment and projects related to education and IT (Rossiyskaya Gazeta, 2012). As a result, the following was achieved:

- Specific educational and research centres equipped with high-tech nanotechnology equipment were established at 40 Russian universities;
- 15 databases on nanotechnology were put together, including the database of 923 Russian organisations that do commercial activities in the nanotechnology sector;
- Multimedia educational complexes were created for educational purposes.

The Mega-grant programme that aims to attract leading scientists from abroad to Russia also targets facilities. The leading scientists that come to work in Russia are funded generously to establish labs, clean rooms and science centres. The execution of the programme is not without issues. For instance, it is not clear what happens to the newly established labs after two years, which is the duration of mega-grant allocation (Kralnova, 2011).

The infrastructure for nanotechnology research relies on the Soviet-inherited concept of 'scientific schools' and the 'centres of excellence'. These centres benefit from the development programmes, whereas the problem of aging equipment in other research organisations is a serious problem. Despite the effort to fund nanoscience, support for facilities and equipment remains an ongoing challenge. Professor Pudalov (2013) from RAS stresses that the lack of proper equipment for applied research is a major impediment for Russian nanoscience.

The National Nanotechnology Network (NNN), formed as a part of the realisation of NNI, unites 50 organisations, including 40 universities and 10 research institutes. The head organisation is Lukin Institute of Physics Problems. NNN members produce 25% of all patents and 50% of all nanotechnology products.

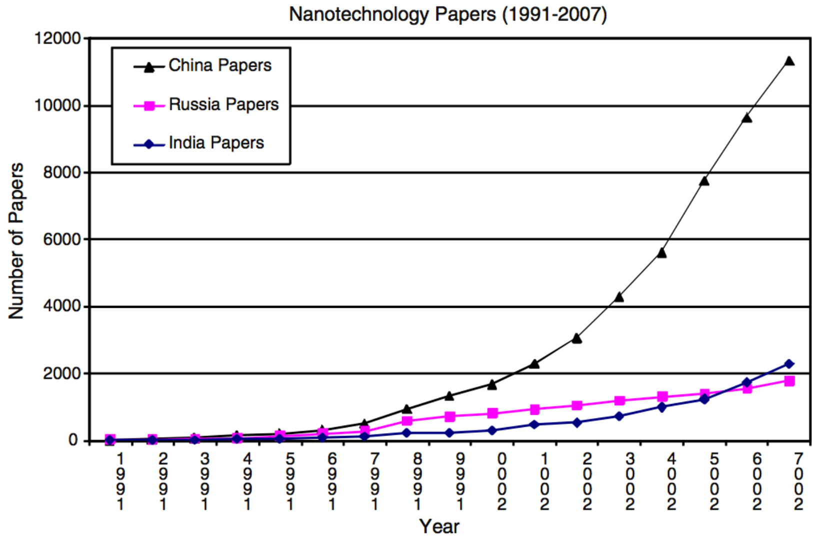
Public Dissemination and Communication Platforms include the Nanotechnologies and Nanomaterials portal, the Nanotechnological Society of Russia, Nanotechnologies News from Russia, the RUSNANO website, the RusNanoNet website, and Russian journals on nanotechnology. Several Russian Technology Platforms (TP) include aspects of nanotechnology, for example the TP on photonics or the TP on LEDs and composite materials.

4.4 Output and performance

Available statistics indicate that Russia's domestic R&D expenditure for nanotechnology grew by one third in 2008-2010, while employment in the nanotechnology sector increased by 20% (Gokhberg et al., 2012). As a priority theme for science in Russia, nanotechnology receives a large public investment. However, prospects for the sustained targeted funding of nanotechnology are unclear, as no updates to the already announced nanotechnology funding programmes have been made.

The continuous government effort to fund basic research and reform the structure of science production system leads to a somewhat increasing trend in the publication output (Figure 1). However, it is not obvious whether it is an inertia trend, or a response to the targeted state policy. Russia tends to focus its funding on the areas that already produce good results and the growth of highly cited and international publications, such as condensed matter physics, material science, chemical physics and spectroscopy. The emerging areas of publications in nanotechnology are nanophotonics, carbon nanostructures and graphene (Terekhov 2011, 2012).

Figure 1 Nanotechnology Papers Produced in China, Russia and India, 1991-2007 (from Liu et al., 2009)



New post-Soviet centres of excellence in nanoscience have emerged. For example research articles produced in Ufa State Technical University of Aviation (UGATU) on bulk nanostructured materials and associated topics that were published in four major journals represent almost 50% of the all-time top-ten most cited publications (Langdon, 2012).

Russian nanoscience still faces several major problems. These include, firstly, Russia's lower growth rate in nanotechnology publications particularly when compared to China (Liu et al., 2009). Also noted are problems of an aging researcher cohort and outdated equipment (Tret'yakov, 2003; 2008, 2009; Gokhberg et al., 2010). While a portion of Russian papers garner citations - Terekhov (2012) found that 1.1% of the highly cited Russian publications provided for 30% of all citations in 1990-2009 – many Russian papers attract little attention. The standing of Russian universities and researchers in international rankings are still low (Klochikhin, 2013).

4.5 International Linkages

Existing bibliometric studies stress the importance of international collaboration in nanotechnology. For instance, Terekhov (2012) notes that internationally collaborated publications with Russian affiliations had twice as many citations compared to publications produced by Russian authors only. This is supported by public policy in its efforts to first bring Russian émigrés back to the country, and, second, by attempting to attract leading scientists from abroad to do research in Russia.

International collaboration, as V.Tretyakov (2007) notes, is one of the popular ways to solve the outdated equipment problem for Russian nanotechnology scientists. Russian scientists use RFBR's specially allocated funds to use diagnostic equipment in research centres in Germany, France, Italy, Belgium, Holland, Japan, and lately in the US.

Despite possible beneficial effects, Russian authors prefer domestic publishing to international publishing. Liu et al. (2009) carried out a comparative analysis of nanotechnology publications in Russia, China and India and found that in Russia domestic journals have higher importance than in the other two countries for publishing nanotechnology papers. This echoes concerns that the Russian science (and nanoscience) system is rather closed and is lacking international cooperation (Klochikhin, 2011; 2013). Internationally collaborated publications in Russia demonstrate significant path-dependencies. Research links developed in the Soviet Union now serve as a main source of international collaboration, where other international links are underdeveloped (Karaulova et al., 2014).

5 Nanotechnology Innovation and Commercialization

5.1 Institutions and organisations

Several new government structures were created after the adoption of the Russian NNI: the Presidential Council on Nanotechnologies and the Government Commission on High Technologies and Innovations within which several nanotechnology working groups were established. The Presidential Council on Nanotechnologies only functioned until May 2008. Currently its functions are partly executed by the Presidential Council for Economic Modernization and Innovative Development. At present there are no special public bodies that supervise nanotechnology development.

The institution of public-private partnerships plays a most important role in Russia's nanotechnology development plan. Prior to 2007, Russian start-up companies had to rely heavily on state funding and were established on the basis of research institutes, often as unitary state enterprises. Examples include NT MDT Ltd., and UNIKhIMTEK Ltd. (Terekhov, 2008).

RUSNANO is a new milestone in Russian nanotechnology commercialization management. It was established on the 19th of July 2007 (Federal Law №139) to assist the implementation of the state policy in nanotechnology. The company's goal is to establish a self-supporting domestic high-tech industry by 2015. RUSNANO draws its funds from Federal budget, but is only able to invest up to 50% of the projects it awards to prevent the spread of the state economy. In September 2010 RUSNANO finished a reorganization and was re-registered as RUSNANO JSC. Now it is a group of companies. RUSNANO JSC acts as a venture capital company for mass-production funding projects in priority areas, whereas the Foundation of the Educational and Infrastructure Projects is responsible for nanotechnology infrastructure, networks and intermediaries, public awareness programmes. The main functions of RUSNANO are the following:

1. Investment activities
    a. Investing in start-ups and business ideas, nanotechnology commercialization tenders;
    b. International markets development to create interest to Russian nanotechnology products abroad;
    c. Market analysis by developing roadmaps of nanotechnology.

2. Infrastructure Activities
    a. Technological infrastructure development;
    b. Standardisation and certification;
    c. Human resources development;
    d. Metrology;
    e. Demand stimulation;
    f. Cooperation in legislative activities
3. Education and Popularisation Activities
    a. RUSNANO Summer School on Nanotechnologies;
    b. Exhibitions, Forum participation and other types of public engagement;
4. Regional Development Programmes

Universities participate in commercialization as well as private companies, and mostly without the mediation of RUSNANO. An example is the development and commercialization of scientific discoveries in UGATU, which commercialized its research and founded a start-up company NanoMeT Ltd. in 2008 to manufacture dental implants (Reshetnikova et al. 2011). Gokhberg et al. (2012) determined that R&D organisations specialize in research-intensive commercialization: they produce 44% of all Russian elementary nano-objects and nano-devices, most unique prototypes and small-scale pilot series of nano-products.

5.2 Nanotechnology Infrastructure

In 2008, policymakers judged that the existing innovation infrastructure in Russia was not developed enough to accommodate the rising needs and challenges of nanotechnology. The NNI hence tasked RUSNANO with building up Russian nanotechnology infrastructure. In most cases RUSNANO chose to use the space provided by scientific cities and technoparks to establish its centres and carry out the activities.

There are several pre-RUSNANO organisations and some infrastructure in place. The amount of investment into those organisations does not equal RUSNANO's, so they found themselves pushed off to the periphery. One example of a pre-NNI nanotechnology commercialisation intermediary is Nanoindustriya Group which has been active since 2001 and sets as its goal as "to develop competitive nanotechnology production, its manufacturing and consumption".[2] The company was the first initiative to establish a nanotechnology production and research equipment supplier.

Public intermediaries, such as the International Science and Technology Centre (Moscow, Russia), help commercialise scientific developments. Communication platforms are being formed by top-down efforts and are mainly state-financed. RUSNANO organised an annual nanotechnology conference in 2008-2011. Currently it is included as a section into RUSNANO's new annual event called 'Open Innovations'. There are older NGOs that attempt to build communication spaces for

[2] http://www.nanotech.ru/pages/about/inat.htm

nanotechnology developers. One example is the National Nanoindustry Association,established during a specialised conference in 2006.[3]

5.2.1 RUSNANO Infrastructure Activities

The bulk of RUSNANO's activities is directed towards developing nanotechnology infrastructure in Russia at Federal and regional levels. RUSNANO has developed nanotechnology roadmaps for nuclear energy complex, space industry, aviation, healthcare and pharmacy, energy saving, water cleaning, LED technologies, catalysts for oil refining, and carbon fibres[4].

The RUSNANO Fund for Infrastructure and Educational Programmes stimulates nanotechnology infrastructure building jointly with Federal and Regional government and with private investors. Its nanotechnology centres serve as incubators for start-up companies and prepare small innovative companies for market entry. Nanocenters are selected through tenders organized by the Fund for Infrastructure and Educational Programmes. By the end of the first quarter of 2012, twelve projects were selected. Their budgets total $930 million, of which RUSNANO financed $450 million. Eleven nanotechnology centres will be constructed during this project.

The fund also performs capacity building activities: programmes in skill development and advanced education, foremost for employees of RUSNANO's portfolio companies. For instance, throughout March 2012 the fund sponsored 63 programmes in which 1,100 individuals participated.

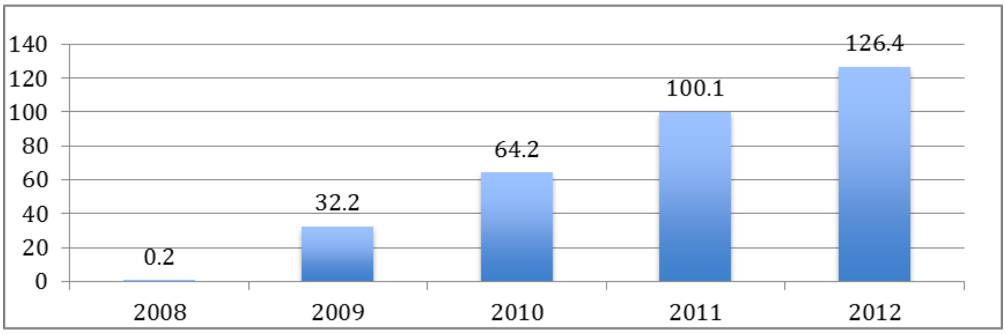
RUSNANO is acting in the regions as a part of its mission to develop nanotechnology markets. Main instruments there include public contracts with regional governments to utilise nanotechnology products, and public procurement[5].

5.3 Output and Performance

Public investment in nanotechnology is growing, and it makes Russia comparable with other leading countries (Figure 2). However, it is too early to assess the outputs of these latest rounds of investments. In nanotechnology development, Connolly (2013) notes that the private sector activity was and still is limited, and "RUSNANO's remit effectively covered the creation of an entire industry almost from scratch". (p.7) The input of RUSNANO and its role in Russia's nanotechnology industry development must not be underestimated.

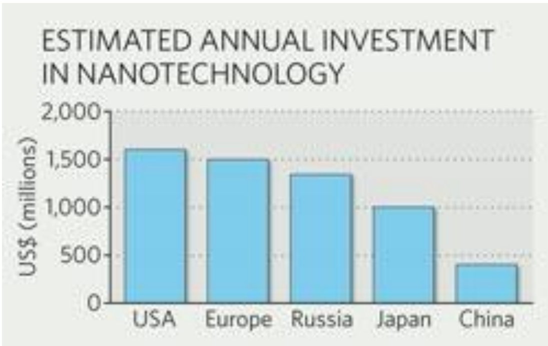
Figure 2 Estimated Annual Investment in Nanotechnology, 2010 (from Nature 2009a)

[3] http://www.nanotech.ru/nan/
[4] RUSNANO Roadmaps are available at http://www.rusnano.com/investment/roadmap (in Russian)
[5] For more details see the "Regional Products of Demand Stimulation" at the RUSNANO website: http://www.rusnano.com/infrastructure/solutions/region.



One of directions of RUSNANO's policy is to foster domestic markets for nanotechnology production through demand stimulation techniques. It is engaged in large-scale projects with Gazprom and Russian Railways for the purpose of modernization of some of their facilities. Over the course of 5 years since establishment RUSNANO signed 105 investment agreements worth of RUB 480 billion, out of which RUB 204 billion was invested by RUSNANO. 76% of the projects are situated in Russia and 16% are in the USA (Figure 3).

Figure 3 Annual Project Investment by RUSNANO 2008-2012 (billion Rubles) (RUSNANO, 2013)



Russia is still lagging behind the other 'BRIC' (acronym for Brazil, Russia, India, and China) countries in terms of patent applications growth (Liu et al. 2009). From 2000 to 2007 there was a surge in the applications in China - 12.8 times - and in India - 8 times, whereas in Russia it was only 1.6 times. In Russia there were 23,377 patent applications in 2000 and 25,598 in 2009, so the increasing trend is minimal (World Bank 2012).

There is evidence that Russian nanotechnology markets are still mostly dominated by conventional products manufactured with the use of nanotechnology-enabled processes (92.1% of manufactured goods in 2009) rather than by radically innovative products. Nanomaterials are present in 7.2% of manufactured products (Gokhberg et al. 2012). Output figures in nanotechnology production, patent applications and nanotechnology sales are growing, but it is debatable whether the growth is adequate to the investment. A cause for concern is also that the manufacturing of products using nano-components or nanotechnology-enabled processes mostly occurs in medium low-tech sectors (Ibid.).

5.4 International Linkages

Nanotechnology is seen to have capabilities to enhance and diversify the export potential of the economy. The government endorses this point of view repeatedly and has aspirations to diversify Russia's export with nanotechnology products (Government Session No15, May 16 2013). It is one of RUSNANO's targets to look for opportunities for Russian nanotechnology-enabled products abroad. Two daughter companies were established to supervise international projects: RUSNANO USA and RUSNANO Israel.

There are more international patents applications for Russian scientific discoveries than there are domestic ones. Terekhov (2008) calculates that there are more US patents with at least one Russian assignee than there are Russian patents issued in Russia. Scientists prefer to sell ideas to foreign firms, apply internationally, or apply discoveries abroad.

6 Societal Issues – Public Engagement, Health and Safety

6.1 Nanotechnology Health and Safety

In 2007, the Federal Consumer Rights and Human Wellbeing Department issued regulations concerning the inspection of new products containing nanomaterials, methodological recommendations detailing approval and implementation of the safety of nanomaterials and the conception of the inspection of the toxicity of nanomaterials (Melkonyan and Kozyrev, 2008; Gokhberg et al. 2012). There is also work into health and safety issues carried out in research organisations. RFBR is funding several projects under the related theme, as well as several studies of physical and chemical properties and toxicity of nanomaterials are carried out within RAS (Melkonyan and Kozyrev, 2008).

However, while there are dispersed initiatives, at the time of writing there was no consolidated research programme in Russia to address potential health and safety issues concerning the manufacturing and use of nanotechnology-enabled products. Therefore, relevant research is being carried out, there is no state-led initiative to do so and the potentially hazardous properties of nanomaterials do not have to be tested before application. In general, there has been limited attention by stakeholder groups to research, regulation, and public engagement on health and safety issues concerning nanotechnology. These issues are lagging behind in terms of development and funding, and the commercial promises of nanotechnology for now have overtaken concerns about its potential hazards.

6.2 Popularisation of Nanotechnologies and Engaging the General Public

The general public in Russia has not been found to be opposed to nanotechnologies. The Russian Public Opinion Research Centre (VTsIOM) summed up the results of a survey conducted at RUSNANO's request in April 2008. The majority of the respondents (74%) think that nanotechnology in Russia is developing one way or another, and more than one-third (41%) are interested in its progress. The overwhelming majority of respondents (81%) said that people will benefit from nanotechnology. Half of those polled (52%) would buy nanotechnology products (Tret'yakov and Gudilin, 2009). However, as nanotechnology issues have faded out from public discourse, no further poll studies were carried out.

Given the apparent general public approval of nanotechnology and other pressing environmental and political concerns, the existing NGOs (such as Greenpeace) do not have the resources to pay sufficient attention to the matter. There is no apparent public demand to take action and investigate potential hazards that surround nanotechnology. The Green political party is currently unpopular as well. In the context of general public approval, and other more immediate concerns, raising health and safety concerns around nanotechnology is not seen as a way to win votes.

Information flows come from professionals to 'educate' the general public about nanotechnology and to 'popularise' nanotechnology in Russia, not to respond to criticisms. The source of these information flows is first and foremost, RUSNANO. One of RUSNANO's prioritised activities is education; in particular, the education of schoolchildren on what nanotechnology is, as well as making the general public familiar with nanotechnology and nanotechnology research. The former involves establishing a RUSNANO School League and setting up Summer Schools (2013 – NANOGRAD, 150 schoolchildren and 50 teachers, to develop youth entrepreneurial potential). The latter, besides more conventional participation in business-to-business events, also involves such activities as setting up art exhibitions.

Other actors of the innovation system interact with the general public as well. The Scientific Community publishes specialised periodicals and popular science books, such as *Nanotechnology for All* by M. Rybalkina[6]. There are several popular science web sites dedicated to nanotechnology. They have a diverse range of readers, including scientists, engineers and businessmen. The oldest of these is http://www.nanonewsnet.ru/ (with a version in English). Several platforms were set the task of popularising Russian nanoscience abroad.

7 Challenges

Our analysis of nanotechnology development in Russia leads us to identify a series of challenges and issues. These challenges are summarised below:

- ☐ Information exchange: there have been several cases when Russian scientists collaborating with their foreign peers were arrested for sharing information deemed by the authorities as is important for national security (Bloomberg 2013). This is a major challenge for the development of international linkages, and for attracting scientists from abroad to work in Russia or with Russians.
- ☐ Risks caused by distrust: there is a widespread public imagery that innovation policies, including the Russian nanotechnology programme, were established in order to redirect oil and gas profits for special interests, not to promote general economic development. There have been several incidents of mismanagement of

[6] Link to the online shop, with other publications as suggestions: http://www.ozon.ru/context/detail/id/2427326/ (in Russian)

resources and preferential treatment during tenders, leading to a low level of trust and engagement in much of the private sector and among NGOs.

- The Russian national innovation system suffers from deep-rooted path-dependencies inherited from the USSR. Two legacies that have great impact are: the targeted programmes system (Dezhina, 2007) and the orientation towards 'implementation' rather than 'innovation'. The structure of the targeted programmes means that the state adopts broad overarching policies, some parts of which are prioritised and have additional targeted financing. Dezhina notes that while such a system worked under the Soviet Union, because it had a large amounts of resources to spend, it has become largely ineffective in modern Russia.
- Policies concerning scientific research that prioritise funding of the existing clusters and 'centres of excellence' may cause a state of uneven development. The Russian scientific landscape is characterised by the existence of centres that are continuously well funded, and an outside group of institutes and researchers that are lagging behind.
- Generation gap in nanoscience: Terekhov (2011) points out the increase of the average age of researchers in the Russian Academy of Science, and the low levels of transition of successful Ph.D. candidates to Academy of Sciences institutions or All Russian scientific centres. Younger researchers prefer moving to the private sector or emigration rather than become full-time scientists within the existing public research system. Terekhov stresses that this is a significant the problem for the potential development of nanotechnology in Russia.
- Health and safety research and regulation in nanotechnology is not well coordinated in Russia and is accorded relatively low priority.

8 Perspectives on the Future

In this section, we draw on our research and analysis to consider perspectives for the future development of nanotechnology in Russia. We highlight a series of patterns and trends in research, policy and innovation:

- Nanotechnology industry development is likely to continue to be a target for public policy in Russia. It is still regarded as a useful tool for development of the economy and the rejuvenation of science. However, there have been serious issues with the implementation of the Russian NNI and Strategy 2020. For instance, in April 2013 RUSNANO faced Russian Court of Auditors allegations related to the mismanagement and estimated losses of 2.5 billion Rubles. The issue was raised during the 'Direct line with the President'[7] on April 25, 2013. Vladimir Putin recognised the mistakes made by the company management, but also mentioned that NNI was his initiative and it was impossible to avoid pitfalls in a high-risk industry. The NNI initially was forced into action by then-President Dmitry Medvedev. By attributing Medvedev's actions to himself Putin indirectly admitted that nanotechnology is a promising industry and can contribute to his positive image. This action reassured the stakeholders that under the

[7] On average 4-hour long live session during which the President answered to questions from the citizens from all over the country. This happens once or twice a year.

Presidential protection investments will be prolonged and the development will continue[8].

- A 'Triple Academy Reform' that will unite RAS, RAMS Russian Academy of Medical Sciences), and RAAS (Russian Academy of Agricultural Sciences) was carried out in September 2013. The property of the Academy of Sciences is to be transferred to a specially set up Federal Agency to manage. The aim of the reform is that "scientists should do science and not worry about material issues". This reform is a major reorganisation of the Russian science system and its effects are yet unclear.
- The first political momentum to develop a new system of funding for basic science that would rely not on the targeted programme mechanism, but would be largely grant-based, was set in January 2014. The principles of the reform were to be developed by June 2014 (President of Russia, 2014). This includes the establishment of a new Russian Science Foundation which will be provide basic research funding in the form of more "flexible" and large research grants. Again, the effects of this reform have yet to be seen.
- The strengthening of Kurchatov Institute is envisioned. In December 2012 the Kurchatov Institute signed a Partnership Agreement with 14 other Scientific Institutes on the joint use of its facilities. This will likely strengthen the position of the Kurchatov Institute, as it manages overall funding and facilities, with some of the scientific centres moving away from RAS, which will weaken the Academy.
- Skolkovo is still work in progress after three years. Constant changes of the concept and functions make its role in the innovation system development unclear.

9 Conclusions

Nanotechnology has been at the centre of policy attention in Russia for much of the past decade, and it has become a focus for establishing and rejuvenating the basic infrastructure of the Russian national innovation system. Nanotechnology has somewhat lost its significance in recent rounds of funding programmes and other government plans. Emphases have been made on other future technologies, such as biotechnology, and on traditionally strong research and innovation areas, such as energy.

Russian policymakers continue to maintain a linear understanding of the innovation process, which is reflected in policy documents. There is typically a split between nano-science and nano-technology and public investments occur separately in these two channels. Also evident is the limited effort to establish innovation intermediary organisations, platforms for dialogue (those that are separate for science and for technology), and limitations in information exchange, with RUSNANO acting as the predominant knowledge broker.

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[8] NB: this was a much discussed issue at a time in the context of the prospects of the ex-President Medvedev to stay in public policy. Medvedev built his public image on high tech and nanotechnology initiatives (he was even briefly called 'nanopresident' for his short height in 2007). So therefore Putin took Medvedev's assets to assert his own power. This infers that nanotechnology initiative is an asset, so must be a relative success. The numbers for NNI are not readily available and are not quite transparent, so inferrences like this one is crucial to understand the real situation.

Despite large-scale reforms and programmes, inefficiencies arise, as many of these are disjointed and even contradictory to one another. Recent radical reforms in research funding and the Russian Academy of Sciences have left a large research community in a highly uncertain environment. Whereas this may incur the emergence of stimulating interpretations and organisational innovations, risks are high that developing new routines and establishing pathways in the research, commercialisation and innovation of nanotechnology in Russia is going to take a long time before it bears fruit.

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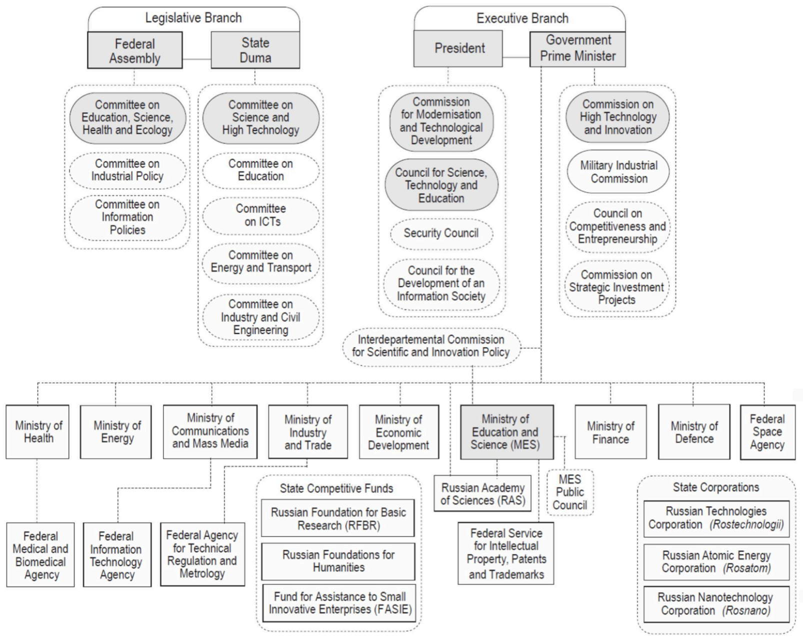
11 Appendixes

11.1 Appendix 1. Public Bodies Responsible for Endorsing Innovation System Development in Russia

Public Body	**Types of Activities**
President of Russia	• Agenda-setting • Priorities setting
Presidential Councils (Presidential Council for Economic Modernisation and Innovative Development, Presidential Economic Council, Presidential Council for Science and Education)	• Presidential advising • Legislative activities • Stakeholder involvement • Public legitimisation and discussions
Ministry of Education and Science	• Science Funding: FTPs • Supervises Public research centres • Legislative Activities • RUSNANO's Education Programmes Participation
Ministry of Economic Development	• Leads Russian innovation strategy 2020 • Supervises State-Owned Corporations and development institutions (including RUSNANO) • Legislation activities • Hears State Corporations' Reports and appoints Directors
Ministry of Defence	• Oversees research carried out in state-owned military laboratories and closed cities
Ministry of Industry and Trade	• Industrial policy coordination
Regional Governments	• Regional Innovation Systems Development • Regional Innovation Clusters

11.2 Appendix 2. Russian System of Innovation Structure: Institutions and Organisations (OECD, 2011)



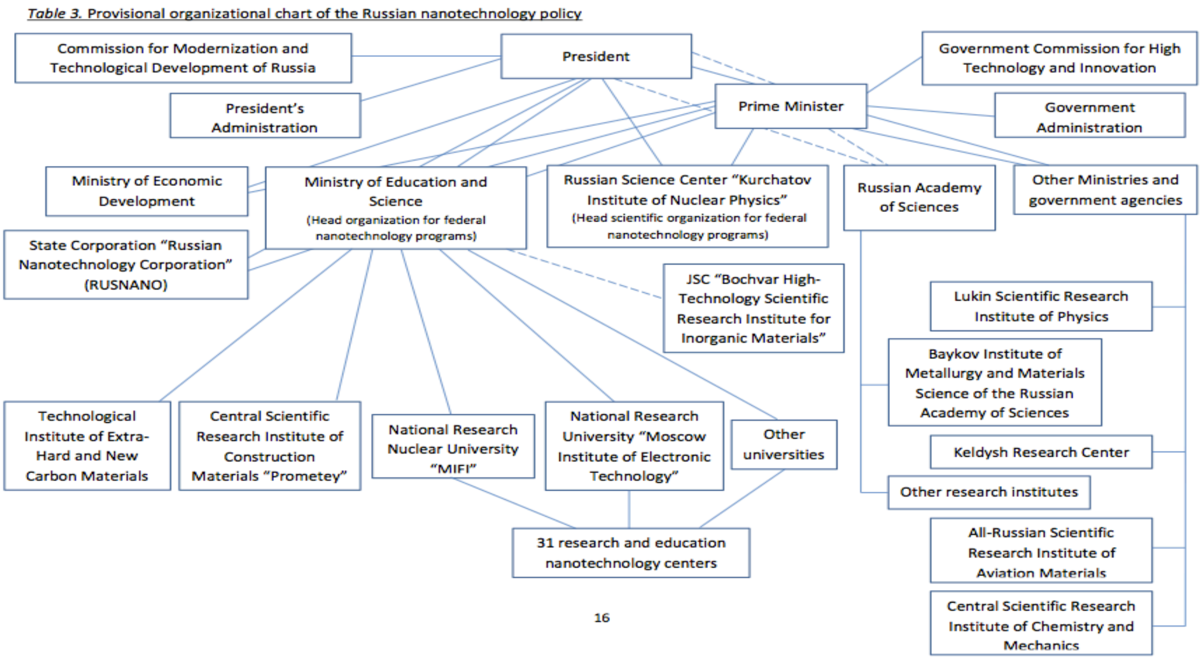
11.3 Appendix 3. Major Russian STI Policies and Programmes to Strengthen Research at Universities and Public Research Institutions (Gershman, Kuznetsova, 2015)

No.	Description of policy	Year of implementation
1	Building a system of national research universities (29 currently) annually evaluated by their performance and largely supported from the federal budget	Since 2008
2	Allowing PRIs and universities to commercialize their scientific outputs through spin-offs	Since 2009
3	Developing innovative infrastructure of universities and their co-operation with industry	Since 2010
4	Attracting leading scientists and PhDs to Russian universities	Since 2010
5	Increasing gross domestic expenditures on R&D to 1.77% of the GDP with the share of universities of 11.4% by 2015	Since 2012
6	Increasing wages of research personnel in public research institutions and universities up to 200% of the regional average by 2018	Since 2012
7	Raising the budgets of public research foundations up to 25 billion rubles by 2018	Since 2012
8	Supporting the leading national universities to enter world's universities rankings	Since 2013

11.4 Appendix 4. Nanotechnology-Related Federal Targeted Programmes (FTP) in Russia

1. FTP Research and Development in the Priority Trends in Science and technology for 2002-2006
    a. Nanotechnology is included in an FTP for the first time in 2004 (Connolly 2013)
2. FTP Research and Development in the Priority Trends of Russia's Science and Technology Complex for 2007-2012.
3. Military Nanoelectronics of the Armed Forces of Russian Federation until 2010.
4. FTP 'Research and Development on the Target Priorities of the Russian Scientific and Technological Complex Development 2007-2012'
5. FTP 'The Development of Nanoindustry in Russia 2008-2011'
6. FTP 'The Development of the Research and Technological Infrastructure for the Russian Nanoindustry for 2007-2009'

11.5 Appendix 5. Organisational chart of Russian Nanotechnology Policy 2010-2011 (Klochikhin 2011)



Manchester Institute of Innovation Research

The Manchester Institute of Innovation Research (MIoIR) is the research centre of excellence in the Manchester Business School (MBS) and The University of Manchester in the field of innovation and science studies. With more than 50 full members and a range of associated academics from across the University, MIoIR is Europe's largest and one of the World's leading research centres in this field.

The Institute's key strengths lie in the linkage and cross-fertilisation of economics, management and policy around innovation and science. Building on forty years of tradition in innovation and science studies, the Institute's philosophy is to combine academic rigour with concrete practical relevance for policy and management. This includes broad engagement with and research for policy makers and societal and industrial stakeholders in the Manchester City Region, across the UK and internationally. MIoIR is also firmly committed to a range of teaching activities within and beyond MBS and integrates a strong and successful PhD programme into its research activities. The Institute has a visitor programme for academics and management and policy practitioners and provides a range of popular and high level executive education courses on evaluation, foresight and S&T Policy.

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