Public policy instruments in (re)building national innovation capabilities: cases of nanotechnology development in China, Russia and Brazil

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Abstract

In 2001 Goldman Sachs named Brazil, Russia, India and China (BRICs) the most rapidly-growing countries in the world capable of surpassing the United States, Japan and Europe as leading economies by 2050.

Nevertheless, for the last decade we have learned relatively little about the mechanisms of success and failure in these countries. All of them have huge territory and population as well as fast-growing economies that sometimes show two-digit rates of GDP growth per year and surprise the world by their increasing budgets and public spending. In the meantime, most of these countries are believed to be desperately struggling against corruption, striking social inequality, uneven development of regions and other socio-economic problems attributable to many countries in the developing world.

In order to tackle these burning issues and ensure stable development the BRICs focus on creating the new innovation-based economies, promote entrepreneurship and support the most advanced technologies by either offering a ‘warm welcome’ to foreign investors or creating their own centers of excellence.

In this context nanotechnology is seen as one of the best platforms to (re)build national innovation capabilities, help break the development lock-in (in Brazil and Russia) or support the weak positive trends towards self-sustained growth (in China).

Major findings of the present study demonstrate that despite the fact that China, Brazil and Russia established their national nanotechnology programs at various times all three countries have formulated full-fledged nanotechnology policies by 2011. This situation is evidenced by the increasing amount of nanotechnology-related R&D spending, patents, publications, involved organizations and researchers. Moreover, all three countries have started creating a national nanotechnology network and founded several specific institutions to support nanoscience and nanotechnology (NST) and help commercialize its applications.

Comparison of chronological frameworks of the countries’ NST public policy initiatives demonstrates relative inconsistencies in actions taken by Russia, Brazil and China. Meanwhile, the United States tries to elaborate a general strategy of nanotechnology development in the years to come.

Finally, the collected data shows that China seems to be more successful in catching up with the United States in the field of nanoscience and nanotechnology as compared to its counterparts – Russia and Brazil. However, there are concerns regarding the quality side of China’s rapid growth.
1. Introduction

In 2001 Goldman Sachs named Brazil, Russia, India and China the most rapidly-growing countries in the world. They predicted that the BRICs will overtake the United States, Europe and Japan as the leading economies by 2050 (Goldman Sachs, 2001).

All four countries of the group have huge territory, large population and persistently high GDP growth rates. Indeed, in the recent decade China five times hit the two-digit growth rates with the peak fixed in 2007 at the level of 14.2%. India has always been around 10%, and Russia’s and Brazil’s development has been unstable ranging from 1.1 to 10% growth (World Bank, 2011).

Nevertheless, despite their many similarities the BRICs remain an extremely diverse group of countries with various cultural and institutional frameworks, political traditions and values, patterns of socioeconomic development. The latest economic crisis demonstrated in 2009 that China and India are capable of sustaining their growth at the level of 9.1% and 7.7% respectively while Russia’s economy fell 7.9% and Brazil lost 0.2% of its GDP.

Moreover, despite their allegedly promising future the four countries continue to fight immense corruption and nepotism, social inequality, poor governance and other socioeconomic problems attributable to many countries in the developing world.

In order to tackle these burning issues and ensure stable development the BRICs focus on creating the new innovation-based economies, promote entrepreneurship and support the most advanced technologies by either offering a ‘warm welcome’ to foreign investors or creating their own centers of excellence.

In this context nanotechnology is seen as one of the best platforms to (re)build national innovation capabilities, help break the development lock-in (in Brazil and Russia) or support the weak positive trends towards self-sustained growth (in China).

Since the announcement of the U.S. National Nanotechnology Initiative in 2000 more than sixty countries worldwide have established similar programmes (Shapira and Wang, 2010; Sargent, 2008). China joined the first group of followers in 2001, Brazil established its nanotechnology programme in 2004/2005 and Russia seems to be the last runner-up in the group with launching its Federal Programme for Nano-industry Infrastructure Development in 2007.

By 2011 Brazil, Russia and China have established full-fledged nanotechnology policies involving dozens of institutions, hundreds of research and education centers and large amounts of R&D spending.

The cases of Brazil, Russia and China are also compared to the control case of the United States as a recognized technological and innovation leader in the contemporary world in order to identify these countries’ major weaknesses and strengths as well as potential competitive advantages.

Understanding the countries’ policy rationale, design and implementation mechanisms will not only uncover the potential of nanotechnology as a platform capable of changing the countries’ development trajectories but also disclose certain important impacts of diverse national innovation system set-ups and environments on producing sustainable innovation in the most advanced technological fields.

Potentially, the present study can indicate similar patterns in other developing countries and emerging markets especially those that can be compared to BRICs by size and population (Asian tigers or Latin American states). Detailed analysis of national innovation systems in Brazil, Russia
and China may also help other countries to tackle similar issues using the findings of this research and adjust their policies to comply with more indigenous environments.

2. Nanotechnology

Nanotechnology is considered to be one of the most promising emerging technologies today. The prognosis of the market size for nanotechnology range between $150 billion for 2010 and $2.6 trillion by 2014 (Hullmann, 2007). All other estimates rush from one extreme to another with the US National Science Foundation expecting $1 trillion market for US only by 2015 and others projecting $1.6 trillion by 2013 (RNCOS Industry Research, 2010) and $2.41 trillion by 2015 (Global Industry Analysts, 2010). Meanwhile, in 2009 the revenues for the nanotechnology and nanomaterials in consumer products were $1.55 billion and are estimated to triple to just about $5.3 billion by 2015 (Future Markets, 2010).

The International Standards Organization (ISO) defines nanoscience and nanotechnology (NST) as the process of “understanding and control of matter and processes at the nanoscale, typically, but not exclusively, below 100 nanometers in one or more dimensions where the onset of size-dependent phenomena usually enables novel applications”. The definition also includes “utilizing the properties of nanoscale materials… to create improved materials, devices, and systems that exploit these new properties” (ISO, 2010). Thirty-six countries already participate in 11 ISO standards on nanotechnology.

Roco (2004) suggested that nanotechnology is going to develop in four successive generations: passive nanostructures; active nanostructures; 3-D nanosystems and systems of nanosystems; and heterogenous molecular nanosystems. The first generation includes applications that are aimed to improve properties of already existent products and create nanocoatings, nanostructured metals, polymers and ceramics. Active nanostructures are capable of self-transformation in the changing external environment. These include transistors, amplifiers, targeted drugs, etc.

The third generation of nanostructures is supposed to present novel applications in the fields of “directed selfassembling, artificial tissues and sensorial systems”, “quantum interactions within nanoscale systems”, “nanoscale electromechanical systems (NEMS)”, etc. The fourth stage of nanotechnology development is believed to start by 2015 and present heterogenous molecular nanosystems, “where each molecule in the nanosystem has a specific structure and plays a different role” (Roco, 2004, p. 896).

Given these prospective nanotechnology applications and unique properties of nanomaterials, the sector is viewed as a platform technology that can be a ‘game changer’ and boost growth across multiple sectors.

As a result, a lot of excitement arose around the nanofield recently with many lobbying groups making governments hastily adopt specialized research programs and launch national nanotechnology initiatives. This in turn put much pressure on policy-makers and scientists with the former having to develop viable development strategies of NST, which could be well-monitored and assessed in the short-, medium-, and long-term periods; while the latter had to hurry to demonstrate that their experiments and findings in the field are worth those huge public and private investments and can guarantee returns in a reasonable time period.

Nevertheless, in recent years there have been concerns about over-hyped nanotechnology discourse. Rip (2010) talks about ‘waiting games’ pointing that NST applications have not met public expectations and key stakeholders sit still now in hope of a breakthrough. Likewise, Roco (2004) suggested that 3-D nanosystems and systems of nanosystems would already be developed by 2010,
which might be quite delayed. In the meantime, some scientists report sensational discoveries based on fraudulent results (New Scientist, 2006).

3. Theoretical foundations

Basically, the goals of the present study require usage of the literature that helps: 1) to understand the best ways to analyse the national innovation capabilities and nanotechnology potential of the selected countries; 2) to identify the criteria to spot the development lock-in and the stages of development that may follow after it has been broken; 3) to analyse innovation and nanotechnology policy in the selected countries and elaborate policy recommendations and possible actions.

In order to achieve these objectives I propose to look at the selected countries and specific field of nanoscience and nanotechnology from the systemic perspective. The basic approaches include:

- the view of development as a systemic process based on three pillars: the government, the market and the community (Kothari and Minogue, 2002);
- the national innovation systems (NIS) approach, which provides a general framework for analysing countries’ institutional, cultural and broader socioeconomic environment (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Edquist, 1997);
- the technological innovation systems (TIS) approach, which focuses on a specific sector or technology – in this case nanotechnology (Carlsson and Stankiewicz, 1991).

So, Kothari and Minogue (2002) elaborate the idea that development is a complex socioeconomic and political process involving virtually all institutions, actors and networks of a country in a systemic and often non-linear way. They point that the patterns of development are much dependent on cultural and historical backgrounds of the nation and in order to break them one will probably need to make changes in all three pillars of the development system: government, market and community. Detailed analysis of these broad pillars may help understand major mechanisms of development, successes and failures in Russia, Brazil and China as well as compare these countries to other, more developed states.

The literature on national innovation systems counts hundreds of articles and books today after Freeman (1987) and Lundvall (1992) first elaborated the concept. Two major streams of understanding national innovation systems developed in the last two decades. The first one is known as the Lundvall-Nelson approach and describes the NIS as a loose institutional structure that enables innovation all across the country’s economy. Education and research play vital role in this scheme. The second approach is more prescriptive and views the system as a combination of specific and visible network connections between institutions and actors (Edquist, 1997).

In the end, both streams consider a NIS to consist of three major pillars: the government, business and academia. The government supports basic science, carries out research and development and formulates and implements research and innovation policies. Business produces innovation, invests in the applied research and ensures competitiveness of the country in the domestic and international markets. Academia conducts broad range of research, provides training to future innovators via universities and consuls other players on policy and strategy issues.

The NIS approach permits to analyse obstacles and facilitators of the innovation process in Brazil, Russia and China at the national level and identify their systemic weaknesses and strengths, which in their turn influence successful development or failure of specific sectors such as nanotechnology. National innovation systems constitute essential institutional externalities to any policy and should be spotted for any path dependences or development lock-ins in order to ensure quality research.
Another theoretical and methodological framework pertinent to this study was developed by Carlsson and Stankiewicz (1991) as the technological innovation systems approach. The authors prescribe that a technological innovation system should be focused on a specific technology and analysed at the structural and functional levels from the point of view of actors, networks and institutions. Actors and networks are identified as key stakeholders in the technology development process with their links and interconnections. Institutional infrastructure is defined as “a set of institutional arrangements (both regimes and organizations) which, directly or indirectly, support, stimulate and regulate the process of innovation and diffusion of technology” (p. 109).

The TIS framework allows to focus directly on nanoscience and nanotechnology and analyse the weaknesses and strengths, opportunities and threats of this specific field in Brazil, Russia and China. The method also helps identify the ways to realize nanotechnology potential as a platform to break the development lock-in or support weak trends towards self-sustained growth.

In the second instance, institutional and evolutionary economics provide several important concepts that help identify specific criteria of development lock-ins and other stages of development that may follow after it has been broken (possible these stages may be united under the term of ‘self-sustained growth’).

Rostow (1956) suggested that a self-sustained growth is defined by the “rise of in the rate of productive investment from (say) 5% or less to over 10% of national income” and “the development of one or more substantial manufacturing sectors, with a high rate of growth” with the political, social and institutional framework quickly adapting to this rapid development (p. 32). Thus, application of these criteria may provide essential markers to spot where countries break their lock-in and proceed to the other stage of development.

Late-development theories can also be quite useful to understand the opportunities and threats of the selected countries in their striving to improve existing development patterns. Gerschenkron (1962) argues that late-development nations (and Russia, Brazil and China can still be considered as such in the contemporary world) have indisputable advantages compared to the leaders as first, they already know the market routes and can invest in the sectors where biggest returns are expected, and second, they do not have the burden of older industries to care about.

However, just having these advantages does not suffice to automatically catch up with and even surpass the leaders. Consequently, Gerschenkron’s theory was later enhanced by the concepts of social capabilities (Abramovitz, 1986) and the capitalist developmental state (Johnson, 1995).

The former suggested that in order to ensure rapid growth and efficient development a nation should first possess or acquire the necessary social capabilities by training new personnel, supporting science, investing in research and development, etc.

The work of Chalmers Johnson (1995) on Japan suggests that the capitalist developmental state (CDS) is based on several crucial pillars which are strong state, effective bureaucracy and economic nationalism. As Russia, China and Brazil may all be considered CDS today these three countries may further be compared in terms of these three pillars as determined by Johnson. Although all of them are characterised by a relatively strong state there are big differences in the level of bureaucracy effectiveness as well as depth and grounds of economic nationalism. While China is proud of its robust labour resources and relatively high level of bureaucratic governance Russia and Brazil lack good control and monitoring system as well as are described as highly corrupt and nepotist countries. Besides, the Chinese economic nationalism is based on big manufacturing potential and rising innovation capabilities while the Russian and Brazilian ideology rests on the rich natural resources (oil, gas, coal) or high agricultural capacity (which though laid foundation for
fast development of biotechnology in Brazil) and occasional sabre-rattling in the international arena.

Given the vital role assigned by the proponents of the late-development theory to the state in promoting rapid development and ensuring catch-up with the leaders, public policy becomes one of the main instruments of transition and growth with the state bureaucracy playing one of the most significant roles in the development process.

There are two major approaches to analysing public policy in this context: ‘structural’ (Chaminade and Edquist, 2010) and ‘functional’ (Bergek et al, 2010).

Chaminade and Edquist (2010) suggest looking at the innovation policy from the institutional point of view in several major areas: infrastructure provision and investment problems; transition problems; lock-in problems; hard and soft institutional problems; network problems; capability and learning problems; unbalanced exploration-exploitation mechanisms; and complementarity problems (pp. 102-104).

Despite its coherence the model would probably be useful as a methodological tool rather than a practical policy guidance. Although it seems quite important to look at innovation through the lens of the systems-of-innovation approach this does not mean that research policy should subdue all other policies that could be equally important for the nation-state. For instance, education policy is very much connected to the innovation policy but still belongs to another political domain with its own goals and mechanisms. Therefore, adopting the systems-of-innovation view straightforwardly should only be possible if innovation is seen by the country's leaders as an ultimate end rather than a means to some other more important objectives like economic growth, poverty reduction, healthcare improvement, etc. Otherwise the policy mix would be seen as a vertical hierarchical model with the research and innovation policy topping the pyramid rather than contributing to the overall process of economic development.

Another group of scholars tried to resolve this problem by adopting more dynamic tools of policy analysis. Dubbing many of institutionalist ideas, Kay (2006) argues that “the dynamic perspective on the policy level of description leads to analysis of contingent conjunctures as opportunities, strategic actions, beliefs about links between action and consequence, as well as preference formation and strategic rationality” (p. 27). Thus, he emphasizes the role of cultural and historical factors.

Kay (2006) also raises the question of path dependence, which must also be taken into account when analysing policy-making and policy implementation mechanisms in Russia, China and Brazil. Path dependences impose critical limits to policy choices, which may seriously hinder the process of breaking the development lock-in and create the situation of double path dependence – both systemic and policy.

In this context Bergek et al (2010) suggest using functional approach to analyse innovation policy in dynamics. They believe that in order to do so scholars need to focus on “key processes rather than states” (p. 121). Processes then are split into two levels: structural (actors, networks and institutions) and dynamic (processes that have direct or immediate impact on achieving the goal of the innovation system). Labelling these processes as 'functions' the authors suggest seven different dimensions where the system should succeed in order to achieve its ultimate goals of supporting and promoting new technology and innovation: knowledge development and diffusion; influence on the direction of search and the identification of opportunities; entrepreneurial experimentation and management of risk and uncertainty; market formation; resource mobilization; legitimation; and development of positive externalities (p. 121).
4. Methodology

The major methods to be applied in the present analysis are documentary review, literature review, content analysis and bibliometrics. This selection might be further enhanced by selected interviews with experts and policy-makers in Russia, China and Brazil in order to better understand the implicit factors of the innovation policy formation and implementation mechanisms. Benchmarking is used to compare Russia, China and Brazil with the control case of the United States to spot major weak points and leeway of their development as well as to identify areas of potential breakthrough.

The key methodological challenges include:

- Lack of English-language literature on the subject and scarce analytical resources in the selected countries due to dispersion and underdevelopment of science study institutions in the countries, virtual absence of relevant databases and episodic collaboration with the Western researchers (with a relative exception of China);
- Scanty nanotechnology-related statistical data both nationally and internationally due to methodological issues (including impossibility to count pure nanotechnology effects on the market);
- Presence of wrong data due to poor quality of available resources and their improper interpretation (e.g. Xuan et al., 2009);
- Most relevant documents and papers on the issue are only available in the native languages of the selected countries, which makes both bibliometrical and documentary analysis almost impossible without due language skills.

5. Case studies

Although China is far ahead other countries of the group in the number of population with 1331.5 million people in 2009, Brazil, Russia, China and the United States are still relatively comparable by territory and growth potential.

So, in 2010 China overtook Japan as the second largest economy in the world and targets to surpass the USA by 2020-2030\(^1\). In 2009 its GDP was 2937.55 billion dollars while America’s one was 11250.7 billion dollars. Meanwhile, Russia and Brazil are definitely lagging behind with 397.95 and 856.02 billion dollars respectively (see table 1).

In the recent decades GDP growth rates demonstrated stability in China often hitting more than 10\% of annual growth. Meanwhile, Russia and Brazil were quite unstable with their growth ranging from 1.1 to 10\% in 2000-2009. Moreover, these two countries were heavily hit by the economic crisis in 2008-2009 while China continued to grow with 9.1\% rates in 2009. The United States also demonstrate persistent stability of growth: its rates often equal 2-3\% although the U.S. economy lost 2.6\% in 2009 because of the financial and economic crisis (World Bank, 2011).

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Table 1. Comparison of major economic and nanotechnology-related indicators of Russia, China, Brazil and United States in 2009

<table>
<thead>
<tr>
<th></th>
<th>Russia</th>
<th>China</th>
<th>Brazil</th>
<th>USA</th>
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</thead>
<tbody>
<tr>
<td>Population (millions)</td>
<td>141.9</td>
<td>1331.5</td>
<td>193.7</td>
<td>307</td>
</tr>
<tr>
<td>GDP (billions, constant 2000 US$)</td>
<td>397.95</td>
<td>2937.55</td>
<td>856.02</td>
<td>11250.7</td>
</tr>
<tr>
<td>GDP per capita (constant 2000 US$)</td>
<td>2805</td>
<td>2206</td>
<td>4419</td>
<td>37016</td>
</tr>
<tr>
<td>Gross R&amp;D expenditure (as % of GDP)</td>
<td>1.24</td>
<td>1.49**</td>
<td>1.02***</td>
<td>2.67**</td>
</tr>
<tr>
<td>Gross nanotechnology-related R&amp;D expenditure (millions US$)</td>
<td>504</td>
<td>220***</td>
<td>27-40***</td>
<td>3700*</td>
</tr>
<tr>
<td>High-technology exports (billions, current US$)</td>
<td>5.11*</td>
<td>381.35*</td>
<td>10.57*</td>
<td>231.13*</td>
</tr>
<tr>
<td>Patent applications (residents)</td>
<td>27712*</td>
<td>194579*</td>
<td>3810***</td>
<td>231599*</td>
</tr>
<tr>
<td>Nanotechnology patents issued</td>
<td>338</td>
<td>97***</td>
<td>6729*</td>
<td>4663***</td>
</tr>
<tr>
<td>Researchers per million population</td>
<td>2602</td>
<td>1071**</td>
<td>629***</td>
<td>4663***</td>
</tr>
<tr>
<td>R&amp;D personnel in the sector of nanoscience and nanotechnology</td>
<td>14500</td>
<td>260***</td>
<td>~150000*</td>
<td>80*</td>
</tr>
<tr>
<td>Number of nanotechnology publications (08.2008-07.2009)</td>
<td>~2700</td>
<td>~20100</td>
<td>1071**</td>
<td>~21000</td>
</tr>
<tr>
<td>Domestic market for nanotechnology products (billions US$)</td>
<td>2.7</td>
<td></td>
<td></td>
<td>80*</td>
</tr>
</tbody>
</table>


* Data available for 2008.
** Data available for 2007.
*** Data available for 2006.

In the meantime, there is vivid difference between Brazil, Russia, China and the United States in the level of GDP per capita, which is significantly bigger in America compared to the other three countries. This indicator reflects the level of human capital development and quality of life, and therefore is very important for understanding the national innovation capabilities.

Another difference between the group of emerging markets and the United States is in the level of R&D expenditure: Russia, China and Brazil spends around 1-1.5% of their GDP on research and development while the U.S. set the goal of spending 3% of GDP for the field (Shapira and Youtie, 2010).

High-technology exports are also quite diverse among the selected countries: Russia and Brazil export 5.11 and 10.57 billion dollars of high-technology production while the United States exports 231.13 and China leads with 381.35 billion dollars. The interesting observation for the latter two countries is that China is rapidly becoming the manufacturing center of the world with a relatively underdeveloped domestic market – that is why it probably has to export so much of its high-technology production. At the same time the United States may be focusing more on the huge domestic market and export only sophisticated products where they have indisputable competitive advantage at the world market.

The United States and China are also way ahead Russia and Brazil in the number of patent applications: the U.S. had 231599, China – 194579, Russia – 27712 and Brazil – 3810 applications by residents in 2006-2008.

Similar diversity is observed among the selected countries in the field of nanoscience and nanotechnology. Nanotechnology-related R&D expenditure varies from 27-40 million dollars in...

Another indicator is the number of issued patents: Brazil had only 97 patents issued in 2006, Russia – 338 in 2009 and the United States – 6729 patents in 2008. The number of R&D personnel in nanotechnology is also quite diverse across the selected countries: Brazil’s Ministry of Science and Technology counted about 260 researchers in the field (Kay, 2008); Russia reported 14500 researchers in 2009 (Rosstat, 2010); and the U.S. had 150000 people involved in nanotechnology in 2008 (Roco, 2010). The number of relevant publications ranges from 1071 for Brazil and about 2700 for Russia to approximately 20100 for China and 21000 for the United States.

Despite the fact that much data is presented here for the selected countries in different years and there are many missing cells because of the data-gathering issues and lack of relevant statistical methodology, the numbers collected demonstrate Russia’s and Brazil’s lag behind China and the United States. Meanwhile, Beijing seems quite successful in catching up with America in the field of nanoscience and nanotechnology with R&D spending, the number of patents and nanotechnology-related publications. On the other hand, it is important to retrieve some more qualitative indicators in order to properly evaluate these large amounts of patents and publications in China as compared to the United States. For example, Shapira and Wang (2010) write that “China is close to the United States in number of publications, but still lags behind the United States and Europe in publication quality” (p. 628). They put the Chinese Academy of Sciences at the 8th place in the number of early citations following major U.S. agencies, UK Engineering and Physical Sciences Research Council, the EU research programmes and the German Research Foundation.

6. Nanotechnology initiatives and policies

The United States announced its National Nanotechnology Initiative in 2000. The European Union, Japan and China were among the early followers establishing their nanotechnology programmes in 2001. Brazil was among the second wave of countries launching its national initiative in 2004/2005. Russia was probably the last in the group adopting its Federal Programme for Nano-industry Infrastructure Development in 2007.

Different timings of establishing nanotechnology programmes may be considered both as a lag in reaction to most recent technology trends and a late-development advantage that potentially provides late-comers with new opportunities elaborated in the Gerschenkron theory.

3.1. China

China started to support nanoscience and nanotechnology development already in 1980s and adopted a 'Climbing-up' ten-year programme in 1990 to provide necessary public assistance for NST research and development. Since then Beijing has been very consistent in its policies aimed to ensure the country's worthy place in the emerging nano-race. In 1999 the Ministry of Science and Technology launched a special research project on 'Nanomaterial and Nanostructure' – the spheres where China has already achieved substantive results. A new institutional framework was created to support the nascent nano-industry with the National Steering Committee for Nanoscience and Nanotechnology to oversee the policy-making and implementation, and National Center for Nanoscience and Nanotechnology co-founded by the Chinese Academy of Sciences in Beijing. Moreover, a large network of research institutions and local agencies was involved into building up the country's innovation capabilities.

Two major programmes were established in China after the United States launched its National Nanotechnology Initiative: the ten-year plan of National Development Guideline for Nanoscience
and Nanotechnology (2001-2010) and the National Development Framework for Nanoscience and Nanotechnology. These programmes were further supplemented by specific strategies adopted by the concerned government agencies and research institutions. Furthermore, they were enhanced by the more strategic Long and Medium Term Science and Technology Development Plan Guidelines for 2006-2020 issued by the Chinese government in December 2005. Importantly, nanotechnology development has become a national endeavour in China with many local universities and provincial authorities engaging into it and investing considerable amounts of money (Tang et al, 2010; Li and Jingjing, 2007).

In general, China chose the technocratic way of creating its own innovation capabilities in the field of NST abandoning the view of several economists who continued to believe that the country should focus on building up its manufacturing capacity employing technology transfer from multinational corporations rather than spending huge sums of money on its own research and development (Appelbaum and Parker, 2008).

In terms of the fourth policy pillar – international collaboration – China is also very active and prolific. It has established network connections with many universities and individual researchers across the globe. For example, an extensive partnership program is sponsored by the US National Science Foundation (NSF) through the Partnership for International Research and Education (PIRE). Returning scientists also retain their international and personal links with the Western universities and organizations, which facilitates institutional-level cooperation like the one created between the Department of Chemistry at the University of California at Santa Barbara, the Dalian Institute for Chemical Physics, University of Science and Technology of China, and the CAS Institute of Chemistry (Appelbaum and Parker, 2008).

3.2. Russia

In early 2000s Russia also engaged into the emerging nano-race. However, it should not be considered an early-comer compared to the consistent policy of China which it has been pursuing for the last 20-25 years. Probably the main difference between Russia and other countries is that it is struggling to recover its innovation capabilities rather than build them up for the first time. Unlike others Moscow witnessed a non-linear scientific and technological development, which was caused by the political and economic plunge of the 1990s. It is obvious that the Soviet Union was one of the first to look into the nanostructures and study the attributes of matter at the scale of 1 to 100 nm. Regrettably, this steady work has been broken after the USSR collapsed but the level of the past research may be proven by the number of high-skilled scholars in the field who migrated to the West and continue to work and write about nanoparticles in the English-language journals. Take for instance Andrey Geim and Konstantin Novoselov – the fresh Nobel Prize winners – who were awarded for their outstanding work on the graphene research, which is part of nanoscience and nanotechnology.

Therefore, now Russia has to work hard with what is left out of its formerly strong innovation system and rebuild network connections between multiple research centers, universities and possibly foreign institutions and former Russian scientists.

Almost immediately after the United States launched the National Nanotechnology Initiative the Russian leaders reacted by including nanotechnology-related research and development into the List of Critical Technologies of the Russian Federation (President of the Russian Federation, 2002). The new edition of the List of Critical Technologies was adopted in 2006 and all the relevant technologies and research were included into the special section under the title of 'Nanotechnology and nanomaterials' (President of the Russian Federation, 2006). In 2004 the Russian government adopted the Concept of Nanotechnology Development until 2010.
In 2006 a special Programme of Coordination of Nanotechnology and Nanomaterials Development has been adopted. The Programme defined the key government agencies responsible for the coordination and promotion of NST development. The Russian Ministry of Education and Science was put in charge of leading, coordinating and implementing the programme thus presaging future problems with progress monitoring and assessment caused by the non-divisiveness of power and control in terms of NST development in Russia. The Russian Science Center 'Kurchatov Institute of Nuclear Physics' became the main scientific coordinator of the program.

Nevertheless, the real work began only in 2007 after President Putin signed the Initiative on 'Strategy of Nano-industry Development' in the Russian Federation. The document ordained the government to develop a targeted federal programme to support nanoscience and nanotechnology and prepare establishment of a new state corporation to facilitate commercialization of scientific discoveries. As a result, in 2007 and 2008 the Russian government adopted a targeted federal programme of Nano-industry Infrastructure Development for the period of 2008-2010 and a Programme of Nano-industry Development until 2015. In July 2007 the new state corporation Rosnanotekh was created to support 'expansion stage companies in commercialization or close to commercialization phase' (Kiselev, 2010). According to its founding documents, the corporation can only participate in co-funding schemes and cannot engage in full-scale investment into start-up companies and sponsor any high-risk basic research. Thus, it is meant to be another instrument of public-private partnership rather than a full-fledged NST support body.

In April 2010 the Russian Prime Minister Putin signed the resolution on creation of the National Nanotechnology Network (Government of the Russian Federation, 2010a). This appears to be another attempt to build up a viable institutional infrastructure that will allow to meet at least any of the goals set in the field of NST development.

In order to enhance international collaboration in the field of nanoscience and nanotechnology Russia established an annual Nanotechnology International Forum since 2008. The Third Forum took place on November 1-3, 2010, and was traditionally addressed by the President of the Russian Federation Dmitry Medvedev. In his concluding speech Anatoly Chubais, the present head of the state corporation Rusnano (formerly Rosnanotekh), told about the main spheres of nanotechnology development in Russia and several success stories that prove its rising potential. Basically, Russia is now focused on the four main sectors where it feels it may occupy a worthy market niche: green, alternative and renewable energy; pharmaceuticals; biotechnology; new materials and technology (Kiselev, 2010).

During his speech on November 3, 2010, Chubais talked in more detail about all these four spheres concentrating on successes in energy efficiency, nanoelectronics, solar energy, nanocoating, nanomedicine, laser-construction and carbon nanotubes. In all these fields, he argued, Russia is undergoing a transition from laboratory research to industrial production.

However, strikingly Chubais was mostly talking about cooperation with foreign companies rather than domestic corporations like PG Photonics or Plastic Logic. The only big project that involves the Russian companies Sitronics and X5 Retail Group is aimed at producing RFID cards for retailing purposes, which does not seem a real innovation in terms of global nanotechnology development. Chubais promised to establish production of such chips at the scale of 90 nm only by 2012, when Russia will be already lagging behind given that most advanced countries are already manufacturing products at 32 and 65 nm (Chubais, 2010).

Thus, despite these bright speeches and optimistic prognosis there are some vivid failures of Russia's nanotechnology development that have surfaced recently and have great impact on its future advancement.
To begin with, Russia was considered a country with the second-largest investment in the field of NST when it decided to put about 130 bn roubles ($4,3 bn) into the newly-established Rosnanotekh corporation. Nevertheless, in two years the company succeeded to spend only 10 bn roubles ($0,33 bn) on the nanotechnology projects of which 5 bn roubles ($0,165 bn) were wasted on its operational costs. As a result, today the Russian government aims to increase efficiency of Rosnanotekh by reforming it into a joint stock company with a separate non-profit Foundation for infrastructure projects.

Another failure could be traced in the reshaping of the Government Council for Nanotechnology, which was created in 2007 to oversee the federal programmes, planning and policy implementation in the field of NST. In September 2008 because of the difficulties in defining the term 'nanotechnology', the Russian Prime Minister renamed the Council into the Commission for High Technology and Innovation. Therefore, nanotechnology was returned into the overall innovation development agenda losing its privileged status.

Furthermore, on June 21, 2010, Prime Minister Putin signed a document prolonging the Federal Programme of Nano-industry Infrastructure Development for the period of 2008-2010 until 2011, which means that the responsible agencies and institutions failed to fulfil the tasks set in 2007, especially taking into account that the document 'played' with the target indicators as well (Government of the Russian Federation, 2010b).

3.3. Brazil

Brazil also proved to react early to the National Nanotechnology Initiative announced by the US President in 2000. Invernizzi (2007) suggests that the talks about consistent NST development at the national level began with a workshop held in Brasilia in November 2000 under the title of Trends of Nanoscience and Nanotechnology. As a result, a special group of researchers was created to review the Brazilian capabilities in the field. In April 2001 they came up with a document suggesting that there are 192 researchers in Brazil working in the following areas: nanoinstruments, nanosensors and nanoelectronics; nanostructured materials; nanobiotechnology and nanochemistry; nanoprocesses and their environmental and agricultural applications; nanometrology (Invernizzi, 2007).

Thereafter there were actually adopted two consecutive National Nanotechnology programmes in Brazil with the first of them abandoned after Lula da Silva was elected the new President in 2002. So, the first National Programme of Nanotechnology was proposed and coordinated by Cylon Gonçalves da Silva who suggested creating a horizontal network model of research centres controlled by the National Laboratory of Micro and Nanotechnology in Sao Paolo. Allegedly the programme was abandoned because of its projected inefficiency and costliness.

The second programme was elaborated later by the working group led by Fernando Galembeck, who proposed to make a more equal distribution of resources all over the country and engage the broad network of local and federal universities and government agencies in the NST development process. So, the new National Programme of Nanoscience and Nanotechnology was discussed and included as an important part of the Multi-Year Action Plan for 2004-2007 and 2008-2011. Respective resources were allocated to NST development at the federal level. Local authorities, universities, research centres and individual companies also included goals related to nanoscience and nanotechnology into their development plans.

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Consequently, four proposals of CNPq (National Council of S&T Development) to create institutional, multidisciplinary networks in the field of nanoscience and nanotechnology were supported by the government in 2001. Four specialized research institutions were created under the Brazilian PADCT S&T Development Programme in 2001-2006: Millennium Institute of Complex Materials, Institute of Nanoscience, Research Network of Systems and Chips, Microsystems and Nanoelectronics, Multidisciplinary Institute of Polymer Materials (Kay, 2008).

Furthermore, nanotechnology was included into the Industrial, Technological and Trade Policy reviewed in 2004. The same year the Brazilian Nanotechnology Network was launched in order to gather institutions and organizations interested in developing NST as a basic research or commercial application in future (Malsch and Valenzuela, 2008).

Brazil also works to enhance international collaboration in the field of nanoscience and technology. In 2003 it engaged with India and South Africa into the so-called IBSA cooperation initiative, which started on June 6, 2003, after the foreign ministers of respective countries signed the Brasilia Declaration. In the aftermath an IBSA Nanotechnology Initiative was launched between the Departments of Science and Technology of India, Brazil and South Africa. The network's activities are mostly concentrated on organizing Winter and Summer Schools for researchers as well as international conferences and web-based courses. However, according to the website, the initiative is becoming more and more passive since 2008⁴.

In 2005 Brazil also launched a nanotechnology research center with Argentina (CBANN), which was considered a successor of similar cooperation initiatives in the fields of biotechnology and nuclear energy (Kay, 2008).

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⁴ For more information see http://www.ibsa-nano.igcar.gov.in and http://ibsa.nic.in/.
Table 2. Comparison of chronological frameworks of nanotechnology development in Russia, China, Brazil and the United States (information on the U.S. is adapted from Sargent, 2008; Roco, 2010; and Forfas, 2010).

<table>
<thead>
<tr>
<th>Year</th>
<th>Russia</th>
<th>China</th>
<th>Brazil</th>
<th>United States</th>
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</table>
| 2000 | • Establishment of the National Steering Committee for Nanoscience and Nanotechnology (NSCNN)  
• Foundation of the Nanotech Industrialization Base of China by MOST | Brasilia Workshop on Trends of Nanoscience and Nanotechnology – a group of experts created to review the Brazilian NST capabilities | • Announcement of the National Nanotechnology Initiative (January 2000)  
• Public R&D spending on nanotechnology equals $270 mln | |
| 2001 | • Launch of the ten-year plan of National Development Guideline for Nanoscience and Nanotechnology (2001-2010)  
• Establishment of the National Development Framework for Nanoscience and Nanotechnology  
• Setup of the Shanghai Nanotechnology Promotion Center | • Report of the group of experts on the NST capabilities of Brazil (192 researchers work in the field)  
• Proposition of two national nanotechnology programmes: Cylon Concalves da Silva vs. Fernando Galemebeck  
• Support of four proposals of institutional, multidisciplinary networks in the field of nanoscience and nanotechnology recommended by CNPq (National Council of S&T Development)  
• Creation of four research institutions under the | • Launching of the U.S. NNI implementation ($464 million allocated)  
• 8 federal agencies involved in the NNI realization: Departments of Defence, Energy and Transportation; Environmental Protection Agency; NASA; National Institutes of Health; National Institute of Standards and Technology; National Science Foundation  
• Establishment of the Nanoscale Science, Engineering and Technology Subcommittee in the National Science and Technology Council’s Committee on Technology  
• Establishment of the National Nanotechnology Coordination Office  
• Opening of the Naval Research Lab’s | |
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Collaboration/Innovations</th>
<th>Institution/Location</th>
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<tbody>
<tr>
<td>2002</td>
<td>NST-related technologies are included in the List of Critical Technologies of the Russian Federation</td>
<td>Establishment of the Network for Computational Nanotechnology</td>
<td>Institute of Nanoscience</td>
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<td></td>
<td>PADCT programme (2001-2006)</td>
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<tr>
<td>2003</td>
<td>Creation of the National Center for Nanoscience and Technology (NCNST) and the National Center for Nanoengineering (NCNE)</td>
<td>• Establishment of the IBSA cooperation initiative (India, Brazil, South Africa)</td>
<td>Adoption of the 21st Century Nanotechnology Research and Development Act (P.L. 108-153)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• IBSA Nanotechnology Initiative launched between the Departments of Science and Technology of India, Brazil and South Africa</td>
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<td></td>
<td>• First evaluation of the National Nanotechnology Initiative</td>
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<tr>
<td>2004</td>
<td>The Russian government adopted the Concept of Nanotechnology Development until 2010</td>
<td>Five-year project launched by the National Natural Science Foundation of China to support the study of the toxicological effects of carbon nanomaterials</td>
<td>First evaluation of the National Nanotechnology Initiative</td>
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<td></td>
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<td>• Adoption of the Multi-Year Action Plan for 2004-2007 and 2008-2011 with the Galembeck version of the National Programme of Nanoscience and Nanotechnology</td>
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<tr>
<td></td>
<td></td>
<td>• Nanotechnology included into the Industrial, Technology and Trade Policy</td>
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<td></td>
<td></td>
<td>• Launch of the Brazilian Nanotechnology Network</td>
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<tr>
<td>2005</td>
<td>• Establishment of the National Technical Committee on Nanotechnology</td>
<td>Establishment of the Brazil-Argentina Nanotechnology Research Center (CBANN)</td>
<td>Opening of the Department of Energy-sponsored Center for Nanophase Materials Sciences at Oak Ridge</td>
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<tr>
<td>Year</td>
<td>Events</td>
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| 2006 | • ‘Nanotechnology and nanomaterials’ section included into the new edition of the List of Critical Technologies of the Russian Federation  
• Adoption of the Programme of Coordination of Nanotechnology and Nanomaterials Development  
• Adoption of the Strategy of Science and Innovation Development of the Russian Federation until 2015 |
| 2006 | • Adoption of the Long and Medium Term Science and Technology Development Plan Guidelines for 2006-2020  
• Launch of the National S&T Development Plan for the 11th Five-year Period |
| 2007 | • Presidential Initiative on Strategy of Nano-industry Development in the Russia Federation |
| 2007 | • Establishment of the Center for Nanoscale Science and Technology (CNST) under the National Institute of Standards and Technology |

(SAC/TC279) under the Standardization Administration of China and located at the CAS National Center for Nanoscience and Nanotechnology
• Foundation of the China National Academy of Nanotechnology and Engineering

National Laboratory
<table>
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<tr>
<th>Year</th>
<th>Events</th>
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| 2008 | - Creation of the Government Council for Nanotechnology (headed by Vice-premier Ivanov)  
     | - Adoption of the Federal Programme of Nano-industry Infrastructure Development for the period of 2008-2010  
     | - Adoption of the Programme of Nano-industry Development until 2015  
     | - Establishment of the state corporation Rosnanotekh  
     | - First annual Nanotechnology International Forum  
     | - Readjustment of the Government Council for Nanotechnology into the Commission for High Technology and Innovation (headed by Prime Minister Putin) |
| 2009 | - Second annual Nanotechnology International Forum addressed by President  
     | - CNST features the Nanofab resource  
     | - Second evaluation of the NNI  

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<th>Medvedev</th>
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<td>• Scrutiny of the Rusnano corporation: Prosecutor General finds bad spending of allocated funds</td>
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<td>2010</td>
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7. Concluding remarks

The findings of the present study demonstrate that all three selected countries have established a full-fledged innovation and nanotechnology policy by the end of the past decade. This policy is facilitated or hindered by many systemic strengths and weaknesses of the respective countries. Brazil, Russia and China try to tackle these problems by applying emerging technologies such as nanotechnology where they can compete from the very beginning. This is especially important for Russia that virtually lost an entire decade of science and technology development in the 1990s because of the complicated transition period.

Collected data also demonstrates that China seems to be more successful in catching up with the United States than its counterparts – Russia and Brazil. However, there are concerns regarding the quality side of its rapid economic growth and soaring number of patents and publications.

In its turn the USA is far ahead its main competitors in the NST field. It invests much more money in its research and development, supports more nanotechnology-focused institutional structures and employs more researchers.

Comparison of chronological frameworks of the countries’ public policy initiatives in the field of nanoscience and nanotechnology demonstrates relative inconsistencies in actions taken by Russia, Brazil and China. Meanwhile, the United States tries to elaborate a general strategy of nanotechnology development in the years to come. Much of this work is based on Roco (2004), Sargent (2008) and Roco (2010). Nevertheless, many predictions made in the early 2000s seem to be delayed because of unforeseen effects. Some experts speculate on this position to prove that the nano-hype is over and we are waiting to engage into the new, more steady and science-based stage of NST development (Rip, 2010).

Further work might include more policy-focused research and detailed analysis and benchmarking of nanotechnology development in Russia, Brazil, China and the United States. The role of NST in breaking institutionally the development lock-in in emerging markets is also seriously understudied. So is overall innovation development and policy of these nations.

Although policy evaluation is not part of this study it might also be interesting to look at the monitoring and assessment mechanisms in the selected countries as they are extremely important for formulating the feedback loop and readjusting policy design and implementation accordingly. For example, the United States carries out reviews of the National Nanotechnology Initiative every three years. Meanwhile, China has a ten-year strategy, and Russia’s key policy-makers and implementers coincide with the major controllers, which makes the entire system almost meaningless (Dementyev, 2009).

References


