PASCC Final Report

Military Applications of Nanotechnology: Implications for Strategic Security I

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Executive Summary

Nanotechnology has emerged as a major science and technology focus of the 21st century. Proponents assert that military applications of nanotechnology have even greater potential than nuclear weapons to radically change the balance of power internationally. The suggestion that nanotechnology will enable a new class of weapons that will alter the geopolitical landscape remains to be realized. A number of unresolved security puzzles underlying the emergence of nanotechnology have implications for international security, defense policy, and arms control regimes.

This research gives the first systematic analysis of this new technology's role and significance in security and foreign policy and contributes to the development of similar frameworks toward designing policy responses to address the promise and perils of nanotechnology, biotechnology, and other emerging sciences. This work accomplished two related ends: review and analysis of the current state of nanotechnology efforts in Russia in the context of military technology development. Although not included in this report, similar reviews by the author were done previously for the European Union and concurrently for China. These analyses are part of a larger comparative effort of nanotechnology for international security, including the United States, Turkey, Israel, Iran, the Republic of Korea, and Singapore.

Second, a set of variables was developed, tested, revised, and assessed in the context of a single foreign state. Limiting the proliferation of unconventional weapons for the 21st century starts with an awareness of the factors driving the capabilities, the changing natures of technological progress and of warfare, and the relationship between science and international security. This work establishes a codified variable approach to the development of strategically significant nanotechnology and emerging science programs, with the eventual goal of enabling cross-national comparisons and an understanding of their impact on security; to better enable mechanisms for the world to govern the implications of its own ingenuity; and to inform security, defense, and foreign policies. Critical factors in the role and significance of emerging technologies (e.g., institutional, ideational, and technical) have been identified.

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Submission of the analytic report of the study's results, which advances critical thinking on the potential role and impact of nanotechnology and emerging science on defense, follows.

Part I. Introduction and the Project's Broader Importance

In order to understand the changing paradigms for national security in the 21st century, it is crucial that policymakers and analysts have an awareness of the factors driving new and emerging capabilities, possess the ability to analyze the changing nature of technological progress and assess potential impacts on the nature of conflict, and understand the relationships among cutting-edge science, advanced technology, and international security. What are the roles and significance of emerging technologies and how should the national security community respond to the promise and perils of biotechnology, nanotechnology, the cognitive neurosciences, advanced information and computing sciences, and other emerging technologies? How will these nascent scientific and technological developments impact local, regional, and international security, stability, and cooperation? What are the most likely sources of technological surprise with the largest threat capacity and how can the national security community better identify them sooner? Emerging technologies present regional security challenges and may exacerbate (or mitigate) the geo-political, military, energy, and economic challenges in the future to a state or region and the potential impacts on U.S. interests and national security. Deep strategic and practical understanding of the significance of emerging technology and its diffusion as well as extending thinking concerning how science, technology, and inter- and intra-national social relations interact to shape and facilitate management of the changing global security landscape is a pressing need for the 21st century. To that end, the Georgia Institute of Technology and the Sam Nunn School of International Affairs was funded to pursue initial research on "Military Applications of Nanotechnology: Implications for Strategic Cooperation & Conflict" to complement the efforts of the Naval Postgraduate School (NPS) and its Center on Contemporary Conflict (CCC) as part of the Project on Advanced Systems and Concepts for Countering WMD (PASCC). Submission of an analytic report of the study's results follows.

Emerging innovations within today's most cutting-edge science and technology (S&T) areas are cited as carrying the potential of bringing the future envisioned to bring both near-term capabilities, as well as those that might appear scientific fictions, closer. Those S&T areas include nanotechnology: robotics, including artificial intelligence; the cognitive neurosciences;

biotechnology, including systems biology; and the intersection of each with information and communications technologies (ICTs).

> *Less predictable is the possibility that research breakthroughs will transform the technological battlefield. Allies and partners should be alert for potentially disruptive developments in such* ***dynamic areas as information and communications technology, cognitive and biological sciences, robotics, and nanotechnology*** *[emphasis added] .... The most destructive periods of history tend to be those when the means of aggression have gained the upper hand in the art of waging war.*[1]

New and unpredicted technologies are emerging at an unprecedented pace around the world. Communication of those new discoveries is occurring faster than ever, meaning that the unique ownership of a new technology is no longer a sufficient position, if not impossible. In today's world, recognition of the potential applications of a technology and a sense of purpose in exploiting it are far more important than simply having access to it.[2] Advanced technology is no longer the domain of the few.

> *"What keeps me awake at night is, are we going to miss the next big technological advance? And perhaps an enemy will have that."*[3]

Anticipating the types of threats that may emerge as science and technology advance, the potential consequences of those threats, the probability that new and more diverse types of enemies[4] will obtain or pursue them, and how they will impact the future of armed conflict is necessary in preparing for the future security of the nation. The potential synergies among the information and communications technologies, biotechnology, and other emerging technologies,

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[1] "Active Engagement, Modern Defence: Strategic Concept for the Defence and Security of the Members of the North Atlantic Treaty Organization," adopted by the Heads of State and Government at the NATO Summit in Lisbon, 19–20 November 2010, http://www.nato.int/strategic-concept/index.html

[2] National Research Council, *Globalization, Biosecurity, and the Future of the Life Sciences*, National Academies Press, Washington DC, 2006.

[3] General Robert Cone, Commander, U.S. Army TRADOC, from Mike Morones, "Interview with GEN Robert Cone," *Defense News*, 16 December 2013.

[4] Beyond traditional state-based adversaries, threats are increasing from non-state actors, including terrorists, see e.g., State Dept, Office of the Coordinator for Counterterrorism, *Country Reports on Terrorism 2012*, Chapter 4: The Global Challenge of Chemical, Biological, Radiological, or Nuclear (CBRN) Terrorism, released 30 May 2013, and other "converging" transnational actors that might seek to acquire and use CBRN weapons.

like nanotechnology and the cognitive neurosciences, not only suggest tremendous potential for advancement in technology for military applications, but also raise new concerns. When asked what are the current approaches and thinking on means for deterring emerging technologies of concern to the U.S., then-outgoing U.S. Strategic Command (USSTRATCOM) Commander General Robert Kehler, U.S. Air Force (USAF), responded, "surprise is what keeps me up at night" and cited current uncertainty in how to assess and address emerging and disruptive technologies.[5] In the 21st century, both nation-states and non-state actors will have access to new and potentially devastating dual-use technology. Intelligence analysts need to be able to understand and appreciate the gaps between the emerging technologies and the operational world that are crucial for devising implementable and executable strategies that will better enable the intelligence community to be prepared for challenges of the future. Robust education and research that bridges the gaps between the life and physical sciences, engineering, the social sciences, and the operational world is crucial for devising implementable and executable strategies that will better enable the U.S. to be prepared for future challenges.

Nanotechnology—which broadly encompasses the design, creation, synthesis, manipulation, and application of functional materials and systems through control of matter at the atomic and molecular levels—is emerging as the major focus of scientific and technological innovation for the 21st century. Although surrounded by popular hyperbole in the 1980s and 1990s associated with the specter of self-replicating assemblers,[6] nanotechnology and related innovations in materials, electronics, optics, biomedical applications, pharmacological formulations, fabrics, and super-strong protective coatings are now coming to practical fruition. Engineered nanoparticles, for example, are currently used in a number of commercial products, including

[5] Comments at the "Sustaining the Triad: the Enduring Requirements of Deterrence" Conference, 8 November 2013, Naval Submarine Base Kings Bay, Georgia. Event was unclassified but not open to the public.

[6] K. Eric Drexler, "Molecular Engineering: An Approach to Time Development of General Capabilities for Molecular Manipulation," *Proceedings of the National Academies of Science (PNAS),* 78, 1981, 5275–5278; K. Eric Drexler, *Engines of Creation*, AnchorPress/Doubleday: New York, 1986; and K. Eric Drexler, "The Road to Advanced Nanotechnologies," presentation at the National Academy of Sciences *Sackler Colloquia on Nanomaterials in Biology and Medicine: Promises and Perils*, Washington, DC, 10–11 April 2007, http://www.nasonline.org/site/PageNavigator/SACKLER__nanoprobes_program

While Eric Drexler has professionally reemphasized the fundamental limits of physics relating to nano-engineered devices, he now emphatically distancing himself from the self-replicating "nano-bots" notion while still advocating for consideration of safety in generation of nano-assembled material, and he acknowledges the unexpected and unintended hyperbole that arose with the "grey goo" concept. Nonetheless, molecular self-assembly remains a topic of popular media, scholarly, and policy discussions.

cosmetics, sunscreens, clothes, photovoltaics (solar cells), sporting good, paints and coatings, pharmacologicals, and electronics.[7] Nanomaterials are being produced on the ton-scale globally.[8] Nanotechnology also is expected to advance medical diagnostics, therapeutics, vaccines, and computing. Proponents assert varying scenarios that nanotechnology will revolutionize life as we know it through economic and global prosperity[9] or that military applications of nanotechnology have even greater potential than nuclear weapons to radically change the balance of power internationally.[10]

For scholars of science and technology studies, the intersection of new technology and weapons application has a rich literature.[11] Within international security, similarly there is a rich literature exploring the intersection of science, technology, and understanding the outcomes of armed conflict.[12] For strategists and scholars of revolutions in military affairs (RMA)[13] and of fourth

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7 National Research Council, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, National Academies Press: Washington, DC, 2006.

8 D Hwang, "Lux Research Nanomaterials: The Rise of MWNTs: Oversupply Hides Real Opportunities," 20 July 2010, http://www.nanolawreport.com/2010/07/articles/carbon-nanotubes/webinar-the-rise-of-mwnts/

9 J Wolfe, "Decoding Future Nanotech Investment Success," *Forbes*/Wolfe Nanotech Report, 10 October 2000, http://www.forbes.com/2002/10/10/1010soapbox.html

10 David E. Jeremiah, "Nanotechnology and Global Security," Palo Alto, CA; Fourth Foresight Conference on Molecular Nanotechnology, 9 November 1995.

11 For example, an incomplete selection includes FA Long and J Reppy (eds.), *The Genesis of New Weapons: Decision Making for Military R&D*, Pergamon Press: New York, 1980; G Spinardi, "Defence Technology Enterprises: A Case Study in Technology Transfer," *Science and Public Policy*, 1992, 19, 198–206; H Gusterson, "A Pedagogy of Diminishing Returns: Scientific Intuition Across Three Generations of Nuclear Weapons Science," in D Kaiser (ed.), *Pedagogy and the Practice of Science: Historical and Contemporary Perspectives*, MIT Press: Cambridge, MA, 2005, 75–107; J Reppy, "Managing Dual-Use Technology in an Age of Uncertainty," *The Forum*, 2006, 4, article 2; BC Hacker and M Hacker, *American Military Technology: The Life Story of Technology*, Johns Hopkins Press: Baltimore, 2006.

12 F Seitz and RD Nichols, *Research and Development and the Prospects for International Security*, Crane, Russak & Company, Inc: New York, 1973; M Van Creveld, *Command in War*, Harvard University Press: Cambridge, 1985; SP Rosen, *Winning the Next War: Innovation and the Modern Military*, Cornell University Press: Ithaca, 1991; EB Skolinikoff, *The Elusive Transformation: Science, Technology, and the Evolution of International Politics*, Princeton University Press: Princeton, 1993; E Solingen, *Scientists and the State: Domestic Structures and the International Context*, University of Michigan Press: Ann Arbor, 1994; J Arquilla, *Networks and Netwars: The Future of Terror, Crime, and Militancy*, RAND Corporation: Santa Monica, 2002; PM Cronin (ed.), *Impenetrable Fog of War: Reflections on Modern Warfare and Strategic Surprise*, Praeger Security International: Westport CT, 2008; and S Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle*, Princeton University Press: Princeton. 2004; TG Mahnken, *Uncovering Ways of War: U.S. Intelligence and Foreign Military Innovation, 1918–1941*, Cornell University Press: Ithaca, 2009; and ME O'Hanlon, *The Science of War*, Princeton University Press: Princeton, 2009.

and fifth generation warfare (4GW & 5GW),[14] the nexus between technology and military affairs is not just speculation but a reality that bears directly on the propensity for conflict and outcomes of war, as well as the efficacy of security cooperation and coercive statecraft. Within today's most cutting-edge scientific and technological innovations—nanotechnology, biotechnology, and the cognitive sciences—emerging research is cited as carrying the potential of bringing the future envisioned in many utopian and dystopian scientific fictions closer. This research probes the potential for transforming the future offense-defense balance in international security, with attendant implications for arms racing, strategic stability, and international efforts to limit the spread of new weapons.

From the chlorine gas attacks of World War I to the use of atomic weapons against Japan in WWII through the biological threats of the Cold War and to the present day, limiting the

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13 SJ Blank, "The Soviet Strategic View: Ogarkov on the Revolution in Military Technology," *Strategic Review,* Summer 1984, 12, 3–90; DR Herspring, "Nikolay Ogarkov and the Scientific-Technical Revolution in Soviet Military Affairs," *Comparative Strategy*, 1987, 6, 29–59; WJ Perry, "Desert Storm and Deterrence," *Foreign Affairs,* Fall 1991, 70, 66–82; AF Krepinevich, "Cavalry to Computer: The Pattern of Military Revolutions," *The National Interest*, Fall 1994, 37, 30–42; J McKitrick, J Blackwell, F Littlepage, G Kraus, R Blanchfield, and D Hill, "The Revolution in Military Affairs," in BR Schneider and LE Grinter (eds.), *Battlefield of the Future: 21st Century Warfare Issues*, Air University Press: Maxwell AFB, AL, 1995; JS Nye, Jr and WA Owens, "America's Information Edge," *Foreign Affairs,* March–April 1996, 75, 20–36; EA Cohen, "A Revolution in Warfare," *Foreign Affairs*, March-April 1996, 75, 37–54; J Arquilla and SM Karmel, "Welcome to the Revolution … In Chinese Military Affairs," *Defense & Security Analysis,* December 1997, 13, 255–269; AH Bernstein and M Libicki, "High-Tech: The Future Face of War? A Debate," *Commentary,* January 1998, 105, 28–31; FW Kagan, "High-Tech: The Future Face of War? A Debate," *Commentary*, January 1998, 105, 31–34; J Arquilla, *Worst Enemy: The Reluctant Transformation of the American Military*, *Ivan R. Dee*: Lanham, MD, 2003; TG Mahnken and JR FitzSimons "The Limits of Transformation: Officer Attitudes toward the Revolution in Military Affairs," Naval War College Newport papers no. 17, 2003, DoD Office of Force Transformation, *Military Transformation: A Strategic Approach*, November 2003; EO Goldman and TG Mahnken (eds.), *The Information Revolution in Military Affairs in Asia*, Palgrave Macmillan: New York, 2004; AA Nofi, *Recent Trends in Thinking About Warfare*, CNA Corporation, September 2006, http://www.cna.org/documents/D0014875.A1.pdf; and TG Mahnken, *Technology and the American Way of War Since 1945*, Columbia University Press: New York, 2010.

14 WS Lind, "Defending Western Culture," *Foreign Policy*, Fall 1991, 84, 41–50; WS Lind, K Nightingale, JF Schmitt, JW Sutton, and GI Wilson, "The Changing Face of War: Into the Fourth Generation," *Marine Corps Gazette*, October 1989, 2–11; TX Hammes, "The Evolution of War: The Fourth Generation," *Marine Corps Gazette,* 1994, 35–41; WS Lind, "Understanding Fourth Generation War," *Military Review*, September-October 2004, 84, 12–16; GS Katoch, *Fourth Generation War: Paradigm For Change*, Master's Thesis, Naval Postgraduate School, Monterey, CA, June 2005, http://handle.dtic.mil/100.2/ADA435502; JW Bellflower, "4th Generation Warfare," *Small Wars Journal Magazine*, February 2006, 4, 27–33; TX Hammes, *The Sling and the Stone: On War in the 21st Century*, Zenith Press: Minneapolis MN, 2006; TX Hammes, "Fourth Generation Warfare Evolves, Fifth Emerges," *Military Review,* May-June 2007, 14–21; T Benbow, "Talking 'Bout Our Generation? Assessing the Concept of 'Fourth-Generation Warfare,'" *Comparative Strategy*, March 2008, 27, 148–163; MJ Artellia and RF Deckrob, "Fourth Generation Operations: Principles for the 'Long War'," *Small Wars & Insurgencies*, June 2008, 19, 221–237; JF McKenzie, Jr., "Elegant Irrelevance: Fourth Generation Warfare," *Parameters*, Autumn 1993, 51–60; and JA Echevarria, *Fourth Generation War and Other Myths*, November 2005, Strategic Studies Institute, U.S. Army War College, Carlisle, PA.

proliferation of unconventional weapons enabled by technological innovation has been and remains a significant international issue. The last decade, however, has brought an intersection of two key drivers that suggest the need for new ways to understand and assess the implications of new and emerging technologies and the potential ramifications for proliferation of new and unconventional weapons. The first, the changing nature of global security threats, began with the fall of the Soviet Union and was punctuated by the terrorist acts of September 11, 2001. Second is the shifting nature of technological progress, which brings entirely new capabilities, many of which are no longer the exclusive domain of a few large states. These drivers offer new opportunities and new challenges for defense, arms control, nonproliferation, cooperation, and the security community.

In the post-Cold War environment, possessing the most technologically advanced military power no longer guarantees national security. Globalization and the information revolution, including the Internet and other communication leaps, have led to much greater visibility into the availability and potential for technology.[15] New technological developments have become accessible and relatively inexpensive to a larger number of nations and within the grasp of non-state actors; advanced technology is no longer the domain of the few.[16] In the 21st century, both nation-states and non-state actors may have access to new and potentially devastating dual-use technology.[17] Nanotechnology is one such emerging technology that has dual-use applications.[18] Understanding these changing paradigms and limiting the proliferation of unconventional weapons for the 21st century starts with an awareness of the factors driving the capabilities, understanding the underlying science and the challenges of defense, considering the changing

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[15] JK Rennstich, *The Making of a Digital World: The Evolution of Technological Change and How It Shaped Our World*, Palgrave MacMillan: New York, 2008.

[16] Office of the Director of National Intelligence, "Unclassified Key Judgments of the National Intelligence Estimate, 'Prospects for Iraq's Stability: A Challenging Road Ahead,'" 2 February 2007.

[17] National Research Council, National Academy of Sciences, *Biotechnology Research in an Age of Terrorism*, National Academies Press: Washington, DC, 2004, and National Research Council, National Academy of Sciences, *Globalization, Biosecurity, and the Future of the Life Sciences*, National Academies Press: Washington, DC, 2006.

[18] For this research, dual use and the dual-use conundrum refers to the fact that almost all the equipment and materials needed to develop dangerous or offensive agents, particularly biological and chemical agents, have legitimate uses in a wide range of scientific research and industrial activity, including defensive military uses. Within this text it does not refer to the demarcation between civilian and military uses.

nature of technological progress and the changing nature of warfare, and the relationship between science and security domestically and internationally.

Communication of those new discoveries is occurring faster than ever, meaning that the unique ownership of a piece of new technology is no longer a sufficient position, if not impossible. It is widely regarded that recognition of the potential applications of a technology and a sense of purpose in exploiting it are far more important than simply having access to it today. [19] Technological surprise has and will continue to take many forms. A plethora of new technologies are under development for peaceful use but may have unintended security consequences and will certainly require innovative countermeasures. For example, tremendous developments in biotechnology have occurred since the advent of recombinant DNA and tissue culture-based processes in the 1970s. If the potential for biotechnology to affect fundamental security and warfighting doctrines had been more clearly recognized twenty years ago, the situation today could be very different. Defense against biological weapons—from both state and non-state actors—currently presents a threat that is difficult to predict and for which traditional solutions are increasingly less effective. In a parallel way, nanotechnology has arisen as a rapidly emerging and well-funded discipline that has been painted as a ground-breaking technology with potential for unpredictable harm.

Reducing the risk from misuse of technology will mean consideration of the highly transnational nature of the critical technology required. Traditional and innovative new approaches to nonproliferation and counterproliferation are important policy elements to reduce the risk of malfeasant application of technology that may enable advanced weapons or make production or dissemination of biochemical agents available to a much wider group of actors. Efforts to strengthen existing international regimes to control transfers of dual-use materials are important.[20] Verification still remains a technical as well as a diplomatic challenge. The role of international agreements and cooperative programs in the 21st century is a contested intellectual and policy field.

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[19] General Charles C. Krulak, USMC (ret), "The Strategic Corporal: Leadership in the Three Block War," *Marines Magazine,* January 1999.

[20] Margaret E. Kosal, "U.S. Policies to Reduce the Threat of Chemical Terrorism," Prepared for The Partnership for a Secure America, 9/11 + 6 Initiative Foreign Policy Priorities for a Secure America, May 2008.

The research underlying the findings in this report, which are part of a larger program, were based on a variety of sources: prior scholarly and technical analysis and study, commercial reporting, government documents, field research, and in-person meetings. Of particular importance was attendance at international scientific meetings at which basic and applied scientific research was presented, such as the Nanotechnology for Defense (NT4D 2013) conference in Tucson, Arizona, and the Second International Conference on Advanced Complex Inorganic Nanomaterials (ACIN 2013) in Namur, Belgium.

The Nanotechnology for Defense (NT4D) Conference is an annual U.S. domestic event bringing together scientists and engineers from defense service laboratories (U.S. and allies), universities, small business, and industry who are working on applications of nanotechnology for national defense capabilities. Initiated a decade ago by the Air Force Research Laboratory (AFRL), Army Research Laboratory (ARL), the Office of Naval Research (ONR), the Defense Threat Reduction Agency (DTRA), and the Defense Advanced Research Projects Agency (DARPA), the NT4D Conference remains the premier event to address emerging and nanotechnologies for defense.

The Second International Conference on Advanced Complex Inorganic Nanomaterials (ACIN 2013) provided an excellent perspective internationally into state-of-the-art work being performed in one area (therefore a "boundable" problem set) of nanotechnology research. Highlights with military applications included:

- Spintronics, i.e., spin transport electronics, i.e., using the inherent spin of electrons and magnetic moment, in metals usually, to move electrons [charge] where and how you want it;
- Synthesis and coagulation activity of polyphosphate-coated silica nanoparticles to stop hemorrhages and uncontrolled bleeding, i.e., improvements on the type of materials used in HemeCon and Q Quik Clot, which have previously been used by the U.S. Department of Defense;
- Porous coordination polymers and metal organic frameworks, i.e. designing and assembling molecular scale Tinkertoys that do things such as store, transport, catalyze, or separate other gas or liquid molecules;

- Atomic understanding of nanomaterials, which featured research on novel ways and novel applications of traditional means to understand the basic structure of nanomaterials;
- Next generation optical storage using gold nanorods;
- New research on harnessing the triboelectric effect, which is the charge generated by the friction of two materials rubbing, sliding, and/or rotating against each other. Moving beyond piezoelectrics. Generating power from motion of life, i.e., nanomaterials in soles of shoes as one walks or woven into backpack as one walks. Usually the energy generated is just lost as heat; these materials convert the energy generated to electric charge that can be captured or stored, as in a battery, or used for things like generating light or amplifying sound;
- Miniaturized—micro- and nano-scale—generators of electricity from piezoelectric, piezotronic, and triboelectric materials. These are the kind of breakthroughs in energy generation and storage that are necessary (but not really possible through traditional macro- and meso-scale batteries) to enable swarming capabilities; and
- Synthesis, characterization, and *ab initio* modeling of asymmetric-substituted metalloporphyrins for dye-sensitized photovoltaics (solar cells) on nano-structured TiO2 substrates.

Participation in ACIN 2013 enabled discussions with researchers from the Gubkin Russian State University of Oil and Gas Center for NanoDiagnostics; the Russian Academy of Sciences; the Baikov Institute of Metallurgy and Materials Sciences; the Tomsk University Institute of Catalysis; Tomsk State University; Lomonosov Moscow State University; St Petersburg State University; Novosibirsk State University; National Research Nuclear University (MEPI); St Petersburg State University of Information Technologies, Mechanics and Optics; Bauman Moscow State Technical University; and the Chelyabinsk State University.

Part II. Overview of Russian Technology Development

Major Scholars

When examining the literature about Russian innovation, it is difficult to separate scholarship produced during the Cold War from contemporary literature. This is a consequence both of the remnants of Soviet government (people, institutions, structures) and culture that color the Russian Federation today as well as the sheer volume of literature on the subject produced by military and academic scholars during the decades-long arms race. This section will attempt to outline the variety of approaches to this topic that have helped shape both Western and Russian scholars' understanding of these phenomena. It will begin with a brief overview of scholarship about the Soviet process of innovation and then summarize the work of contemporary scholars attempting to make sense of the current Russian system of innovation.

Scholarship regarding military and technological innovation within the Soviet Union provides an interesting insight into the evolution of Western opinions toward Russia. Many scholars, as exemplified by those at the academic-policy intersection, such as McNamara, Kaysen, and Rathjens,[21] center their theories about Soviet innovation squarely in the predominant theoretical model of the time: realism. All three of these men—like many other realist scholars—approach their subject with a particular conceit; they believe that the arms race between the United States and Soviet Union stemmed from a sense of competition between the two states, and wrote dozens of articles illustrating how this model shaped the politics of the Cold War and how it should shape relations between the two countries in the future. Beginning in the 1970s, however, another program of research began to emerge on this subject. Rather than focus on the military capabilities of individual countries, these scholars sought to understand the connection between a state's military innovation capabilities and various cultural factors. Adam Grissom's review of the literature in this area examines six avenues: civil-military, intraservice, interservice, cultural, top-down, and bottom-up.[22] Many later prominent scholars of Soviet military innovation fall

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[21] Carl Kaysen, Robert S. McNamara, and George W. Rathjen, "Nuclear Weapons After the Cold War," *Foreign Affairs,* Fall 1991, 70 (4), 95–110.

[22] Adam Grissom, "The Future of Military Innovation Studies," *Journal of Strategic Studies,* 2006, 29 (5), 905–934.

squarely into the cultural sector of research. Dima Adamsky attributes the pattern of Soviet innovation following American innovation to the structure of the Soviet military itself. In his view, the highly centralized, administrative structure of the military meant that any decision to begin development of a new weapon or weapons system came from the military.[23] As such, Soviet military innovation was entirely dependent on the leaders' perception of American military strategy. Matthew Evangelista, as an example of another approach, also attributes Soviet innovation to a set of particular cultural ideals, but he focused on how these ideals were codified in the larger structure of the Soviet military.[24] His work is particularly interested in the intersection of the Soviet military's tradition of suffering as a precursor to strength and forbearance and the prevailing political notion of communism. It is here, in this gray area, that one is able to account for the Soviet military's inability to capitalize on its understanding of the coming revolution in military affairs (RMA) that the leadership predicted but could not implement.

Scholarship about contemporary Russian innovation draws heavily on existing commentary on innovation in the Soviet Union. This is largely due to the hybrid nature of the current government structure. Slavo Radosevic, a prolific author on this subject, attributes the current state of the Russian government to the country's conflicting desires to both retain the remnants of the Soviet Union in the government structure and to reform the government entirely.[25] As such, authors seem to find it difficult (or impossible and ahistorical) to explain the Russian government of today without accounting for its past. Uvarov Alexander and Perevodchikov Evgeniy attempt to synthesize many of the Russian government's current innovation efforts by examining recent legislation attempting to generate ties between the primary engine of innovation in both the Soviet Union and the Russian Federation—the independent research institute—and universities.[26] The difficulty of enacting such change, which seems utterly logical

[23] Dima Adamsky, *The Culture of Military Innovation: The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the US, and Israel*, Stanford University: Stanford, 2010.

[24] Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies*, Cornell University: Ithaca, 1988.

[25] Slavo Radosevic, "Patterns of Preservation, Restructuring, and Survival: Science and Technology in Russia in post-Soviet era," 2003, *Research Policy*, 32, 1106.

[26] Uvarov Alexander and Perevodchikov Evgeniy, "The Entrepreneurial University in Russia: From Idea to Reality," *Social and Behavioral Sciences*, 2012, 52, 47.

to a Western audience, takes on an entirely new meaning if the role of the university in the Soviet Union is understood. A. I. Terekhov has also written a great deal on the evolution of science research programs within the Russian Federation.[27] Just as Alexander and Evgeniy's analysis of the current state of Russian reforms is meaningless outside of the context of the Soviet Union, however, so is Terekhov's research in this area reliant upon the past. This is due to the Russian government's desire to capitalize upon the country's enormous population of scientists and researchers and to utilize as much of the research that is already being conducted in its laboratories as possible to further its desired economic growth.

An exploration of the major authors discussing Russian innovation is incomplete without a discussion of the myriad reports being compiled by a number of international organizations. For example, the World Bank's 2011 *Igniting Innovation: Rethinking the Role of Government in Emerging Europe and Central Asia* and the Organization for Economic Cooperation and Development's (OECD's) 2012 *Science and Industry Outlook* are very different from any of the literature mentioned above in that both are less concerned with developing a theoretical model to describe past Russian development than exploring and explaining the mechanisms employed currently. *Igniting Innovation* is particularly useful for placing the Russian Federation's new legislation in context, as it includes a very thorough overview of the major structures within the Soviet process of innovation.[28] Using this structure of as a baseline against which comparisons of the current system can be made, the report reinforces the assertions of authors above that the current understanding of innovation within the Russian Federation is heavily shaped by past efforts. However, it goes on to conclude that the best possible outcome for both the Russian economy and investors is the phasing out of government control in the near future. The *Science and Industry Outlook* provides a number of very specific measures of the success of Russia's new plan to enhance innovation within the country and provides an even greater level of context than the World Bank report by comparing the findings with those of both OECD member states and the BRICS (Brazil, Russia, India, China, and South Africa). The report highlights both the strengths and deficits that exist within the country and provide concrete steps the country can

[27] A. I. Terekhov, "Evaluating the Performance of Russia in the Research in Nanotechnology," *Journal of Nanoparticle Research*, 2012, 14(11), article: 1250, 16.

[28] Itzhak Goldberg, John G. Goddard, Samita Kuriakose, and Jean-Louis Racine, "Igniting Innovation: Rethinking the Role of Government in Emerging Europe and Central Asia," The World Bank, 2011,

take to capitalize upon its existing investment. Amy Beavin, Anna Bryndza, and Andrew C. Kuchins' report for the Center for Strategic and International Studies (CSIS) succinctly outlines the "Concept of Long-term Socioeconomic Development of the Russian Federation," the country's vision statement for its economic growth until 2020.[29] Although ambitious, the concept provides an important insight into the sectors of the economy that the Russian Federation sees as having the greatest potential for growth in the future. Not only does such information provide a vital context for understanding the changes the country is attempting to incite, but the CSIS scholars draw upon studies by prominent Russian venture capitalists to assess how feasible the concept and its projections are. Their findings are discussed in detail in below.

Although the authors and subjects mentioned above are diverse, each fills an important role within the literature at large. The Russian Federation is notoriously resistant to sharing information about the manner in which their government functions, which gives these authors' work an important weight when attempting to ascertain where the Russian Federation is in implementing its plans for the future. It is impossible to synthesize such a large and varied literature without omitting important voices on the subject; however, the authors and reports included above represent the most widely cited papers in this field. As such, the views and arguments can be understood to represent a far larger body of work in each area.

Major Theoretical and Policy Models

Much of the literature summarizing Russian technological innovation is grounded in the decades-long arms race now known as the Cold War. Although the specific details of the cases addressed in these studies may appear outdated, many of these frameworks are useful to the discussion of the current state of innovation in Russia because they provide benchmarks by which one can compare aspects of contemporary Soviet efforts to innovate. McNamara, Kaysen, and Rathjens' analysis will be summarized first as it provides the most the most straightforward understanding of the Soviet Union's impetus to develop new technology. In this model, Soviet and American

[29] Andrew C. Kuchins, Amy Beavin, and Anna Bryndza, "Russia's 2020 Strategic Economic Goals and the Role of International Integration," Center for Strategic and International Studies, 2008.

leaders were locked in an endless cycle of one-upmanship that the authors refer to as the "action-reaction" dynamic of innovation between the two states. Adamsky's strategic culture model provides a very different perspective on the matter, focusing on Soviet culture as a whole, while Evangelista's five steps in the Soviet military innovation process provide a framework for analyzing contemporary government attempts to develop new technology. The section will end with insights provided by Slavo Radosevic, who argues that many of the current problems plaguing the Russian government's efforts to streamline innovation lie in its desire to both restructure and preserve aspects of the Soviet government that have endured in the wake of the Soviet Union's dissolution.

Of the authors examined in this section, Kaysen, McNamara, and Rathjens had the most direct experience with American interaction with the Soviet Union during the height of the Cold War. Kaysen and Rathjens both served as members of the Massachusetts Institute of Technology's Defense and Arms Control Program during the 1960s, and McNamara as the United States' Secretary of Defense from 1961–68. It is therefore not surprising to find that their model is the most simplistic in its explanation of Soviet military innovation—the necessity of quick decisions during this time in history made complex models largely unworkable. In an article entitled "Nuclear Weapons after the Cold War," the authors summarize their understanding of the nuclear arms race in one sentence: "The Soviet nuclear buildup was a response to that of the United States."[30] Unlike the other theories presented in this section, the authors give no credence to the idea that one or a number of cultural factors prevented the Soviet Union from implementing the coming military-technical revolution (MTR) that its leaders predicted. Instead, they focus explicitly on how the characteristics of the international political sphere at this time influenced the behavior of actors. The impetus for such high amounts of resources allocated to military technology in both the United States and the Soviet Union was the product of a bipolar world in which military innovation—and especially the improvement of states' nuclear capabilities—was seen as the only means of ensuring national security. Both sides, according to this theory, labored under the constant fear that a "devastating bolt-from-the-blue nuclear attack"

[30] Carl Kaysen, Robert S. McNamara, and George W. Rathjen, "Nuclear Weapons after the Cold War," *Foreign Affairs*, Fall 1991, 70 (4), 96.

might come at any time.[31] Rather than address the problem head on, however, both sides engaged in a variety of political maneuvers including bluffing about the size of their arsenals, which increased tensions on both sides and made competition for the "best" weapons a matter of life and death.[32]

A similar frame of reference appears in a much later article as McNamara attempts to provide guidance on how the United States should address and improve relations with Russia and China in a post-Cold War world.[33] Again, his analysis focuses on the nature of the international system as the foundation of his argument. The United States is the greatest power in the international system, and, as such, is the "winner" of the Cold War. However, Russia's desire to modernize both its military and its economy is credited to a variety of policies and actions that the United States has adopted in the wake of the collapse of the Soviet Union. Also cited are three "betrayals" that occurred during the 1990s and are especially important. The first, America's expansion of NATO in the late 1990s, violated what the Russians understood to be America's promise not to expand the organization eastward in the wake of the Cold War. Not only did NATO expansion break this promise, but it also provided the Russian government evidence that the United States was attempting to contain Russia and limit its influence in Europe despite the Cold War having ended. Secondly, the Russians understood the "Founding Act" of May 1997 as an opportunity to obtain a commitment from the United States and NATO that would "limit the expansion NATO's military capabilities…; disavow any intention to use force against any state except in self-defense or unless authorized by the U.N. Security Council; and grant Russia a role in NATO's political decision making.'[34] Although Russia secured the first two objectives, its failure to accomplish the third led directly to what the authors consider the third betrayal: the bombing campaign against Belgrade.[35] While the West conceived of this bombing as a means of forcing the Serbs to stop the ethnic cleansing of Albanians in Kosovo, Russia understood the bombing as a flagrant violation of the Founding Act. The violation, in combination with the

[31] Ibid., 97.

[32] Ibid., 98.

[33] Robert S. McNamara and James G. Blight, "In from the Cold: A New Approach to Relations with Russia and China," *World Policy Journal,* 2006, 18 (1), 72.

[34] Ibid.

[35] Ibid.

ineffectiveness of the Serbs' military equipment against NATO forces drove the Russian government to improve its conventional weapons so that the country could defend itself against potential NATO attacks with something other than nuclear weapons.[36] While it is beyond McNamara's thesis, improvements in conventional weapons would extend to investment in new materials and capabilities through emerging technologies, like nanotechnology.

While McNamara's theory does provide a reasonable explanation for the Russian government's mistrust of the United States and its intense focus on improving its conventional weapons systems, however, it fails to explain why the Soviet Union was unable to implement the MTR that its leadership predicted was underway during the Cold War. If, like McNamara, Kaysen, and Rathjens contend, the Soviet Union's process of innovation was entirely predicated upon its desire to keep pace with the United States, it seems reasonable to assume that the military would adopt and implement the reforms called for by the General Staff (GS) of the USSR. However, the Russian government chose the opposite approach, choosing to engage with the United States and enter *perestroika*. Neither their early article nor McNamara's 2001 prescription for America's foreign policy toward Russia includes a mechanism to explain this change. As such, it is necessary to explore other explanations of this evolution.

In his book *The Culture of Military Innovation*, Dima Adamsky attributes the differences between American and Soviet military innovation to a series of cultural variables rather than strictly to military competition. Specifically, he posits that "[t]he relationship between technology and military innovation is not deterministic, but rather socially constructed; national military tradition and professional cultures interact with technology, affecting the course and outcome of military change."[37] Adamsky attributes these cultural differences to differences in countries' strategic culture. The cultural differences he measures include high- versus low-context communication and the perception of time. The cognitive variables include holistic versus dialectical thought and logical verses analytical thought. According to this theory, the Soviet Union constituted a "high-context" society that drew frequently on a sense of shared

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[36] Ibid., 72.

[37] Dima Adamsky, *The Culture of Military Innovation: The Impact of Cultural Factors on the Revolution in Military Affairs in Russia, the US, and Israel*, Stanford University: Stanford, 2010, 10.

history and tradition. Individuals in such a culture express themselves "in indirect, reserved, cynical, and vague language, relying on the listener/reader's ability to grasp the meaning from the context."[38] Time is also perceived in a very non-linear manner; individuals' frequent reliance on past experience creates a culture where the present is colored heavily by the past. There is a strong sense that "everything will happen in its time" and that "everything is connected to everything else."[39] Adamsky claims that this understanding of time leads to workplace behavior that is less than ideal for innovation; specifically, he claims that cyclical behavior is common in the workplace, meaning that individuals frequently change from one task to another and, though they may understand a great deal, do not concentrate on any one task for long periods of time.[40]

Adamsky goes on to apply these traits to the Soviet military innovation during the Cold War. He finds that the military leadership's understanding of two particular issues heavily shaped their response to developing their nuclear program. First, increased mobility of tactical nuclear weapons required "friendly forces to be dispersed to avoid enemy nuclear attack."[41] Secondly, the Russians now required maneuver forces to mass and break through the enemy's line without allowing NATO to employ nuclear weapons against them in order to gain ground in an offensive attack.[42] Adamsky traces the roots of truly revolutionary thought to Nikolai Orgarkov, Chief of the General Staff of the Soviet Union, who recognized that the latest technological advances constituted a "genuine discontinuity in military affairs" that required the exploitation of the new technologies to invent new means of conducting military operations.[43] While much of the Soviet military seemed to understand that improving existing and developing conventional weapons provided a more secure means of ensuring second-strike capability, particularly given the precision new technologies allowed, the Soviets ultimately failed in the implementation of the military-technical revolution (MTR). Although the details of the case study are not directly applicable to the present, the mechanisms responsible for Russia's failure to apply the MTR to its military strategy provide important insights into Russia's military.

[38] Ibid., 16.

[39] Ibid., 17.

[40] Ibid.

[41] Ibid., 26.

[42] Ibid., 25.

[43] Ibid., 28.

The first reason Adamsky cites for this failure is the lack of bureaucratic support for Ogarkov's proposals. As the Chief of the GS, Ogarkov had the power and leverage to implement real change in the Russian military's grand strategy. He drew upon a variety of "interrelated professional discussions" about NATO's shift to a "follow-on forces attack," which was designed to attack the enemy as far in the rear as possible.[44] Ogarkov claimed that the improvements in conventional weaponry by both the Americans and the Soviet Union heralded a revolution in military strategy dependent on capabilities. This revolution required the exploitation of emerging technologies to "invent innovative means of conducting operations" and to adjust force build up in each military service.[45] Ogarkov's writing and thinking co-evolved with the Soviet military's gradual recognition that many missions formerly perceived only as nuclear missions were increasingly utilizing conventional weapons as well. Even as many in the Russian military recognized the wisdom of Ogarkov's thinking, he "could not muster necessary support from the Kremlin, Foreign Ministry, or KGB," which ultimately led to his ouster.[46] Without its most vocal leader in a position of real power any longer, the impetus behind the change died.

Ogarkov's failure to garner sufficient bureaucratic support for his ideas is not the only factor in the MTR's failure, however. Adamsky also points to two external factors that colored the general military climate at the time in which Ogarkov's proposals were being circulated. While many general officers in the military agreed with his analysis and ideas, the political climate was changing. Ogarkov served as the Chief of the GS from the beginning of *perestroika*. Not only did civilians rail against the notion of increasing military budgets any further, many members of the government also disagreed. As such, military authorities were unable to exert the kind of authority that they had in the past, which ultimately led the military to ignore Ogarkov's proposals and the end of his military career. The lack of support for these policies may also have stemmed from a variety of economic factors that were becoming increasingly obvious at this time: the Soviet Union never possessed the necessary economic capacity to embark on the kinds

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[44] Ibid.

[45] Ibid.

[46] Ibid., 37.

of "ambitious military transformations" that Ogarkov proposed.[47] As such, even if political will had existed at this time, the country's economic situation made such innovation impossible. While Russia is several decades removed from the specific problems addressed in Adamsky's work, the broad strokes of these issues continue to color the government's policies. As such, the model presented here is more applicable than the time period covered would seem.

The impact of the culture of the Russian military on the failure to implement the MTR using the cultural variables discussed earlier is also important. Given the larger culture's tendency toward collectivism and to the reliance on history and tradition, Adamsky claims that Russian strategic experts saw all problems and issues as interconnected in a single system.[48] Rather than a strategic or tactical puzzle, however, the Russians understood the "problem" to be solved as a moral one. This certitude, combined with a history of suffering domestically and on the battlefield, created a culture that propagated the notion that "triumph over insufferable circumstances encouraged values of self-restraint and moral and physical fortitude."[49] Because suffering was noble and much of Russian military doctrine relied on the notion of human mass as a key to military victory, the Soviet military leadership never succumbed to the "techno-euphoria" that drove the United States to constantly seek the next technological innovation.[50] Adamsky also posits that the Russian military leaders found reinforcement for their actions in the pervasive "Marxist dialectics" within the broader culture. Specifically, he points to Marxism's propensity to exist in an "imagined future" where problems are ignored rather than confronted as a framework for a military that became "good at theorizing innovative concepts but pathologically bad at implementing them."[51]

Three negative cultural impacts that influenced the Soviet Union's ability to implement the MTR are identified. First, Adamsky claims that the authoritarian nature of the Russian culture led to the creation of military leadership, the GS, that was responsible for planning and executing

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[47] Ibid., 38.

[48] Ibid., 43–44.

[49] Ibid., 46.

[50] Ibid., 50–51.

[51] Ibid., 52.

operations, but also for "synthesiz[ing the] insights of military knowledge."[52] One of the GS's primary tasks was to generate revolutions in military affairs and to determine how they could be implemented. The Russian government and Russian military establishment saw the GS as a "brain" that not only commanded operations but also distilled military operations from the general to the particular. Creating an audience for new MTRs or other new ideas was therefore very difficult, particularly given the economic and political climate discussed above. The sense of tradition further manifested itself in the general understanding within the Russian military that saw suffering as essential to producing fortitude among soldiers and that also attributed military success to "men, spiritual power, and psychological factors"[53] rather than to improved weapons technology or any other material component. Therefore, Ogarkov's assertion that the Russian military needed to invest more money and resources into research and development (R&D) to maximize the efficacy of both its nuclear and conventional weapons was not well received. It not only flew in the face of both governmental and public desire, but also in the face of prevailing military tradition. Lastly, the prevailing military dogma of the day, Marxism, may have impacted the military's ability to implement the MTR. The problem, he claims, comes where Marxism and the high-context nature of the Russian culture intersect. Marxism, Adamsky argues, reinforced notions of an "imagined future" and also placed particular emphasis on ignoring rather than fixing problems. As such, the Russian military was very good at "developing revolutionary concepts of modern operations" but never implemented those theories.[54]

Similar conclusions about Soviet military innovation are reached by Matthew Evangelista through a very different process. In his book *Innovation and the Arms Race: How the United States and Soviet Union Develop New Military Technologies*, Evangelista argues that Russia was a "late, late industrializer" that instituted a "costly campaign of forced-draft industrialization," inadvertently creating a highly centralized government and a very weak society.[55] Through exploration of the state's military and history of innovation and comparing it with the United States in regards to centralization, complexity, formalization, interconnectedness, and

[52] Ibid., 53.

[53] Ibid., 55.

[54] Ibid., 56.

[55] Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies*, Cornell University: Ithaca, 1988, 26.

organizational slack, five structural characteristics (variables) "that appear to affect organizational innovativeness" are put forward.[56] Evangelista argues that, after comparing the two states in these areas, the United States' R&D apparatus makes it inherently more innovative because the Soviet Union's "highly centralized, hierarchal," system, "characterized by excessive secrecy and compartmentalization," hinders both its ability to innovate and its ability to implement those innovations.[57] He goes on to distill the military weapons development processes into five steps for both countries and applies those steps to both states' development of tactical nuclear weapons.

Evangelista's first step in Soviet military innovation is known as "stifled initiative." At this early stage in the innovation process, there is evidence of technical antecedents to future military innovations and discussion of possible military applications of emerging technologies. However, this step is also marked by "organizational and systemic constraints preventing the active pursuit of potential developments that do not coincide with existing priorities."[58] This is in direct opposition to the same stage in the American military innovation process that is undertaken after the independent development of new technology by scientists working in private firms within the larger military R&D apparatus.[59] Such independent development is impossible in the strict administration of the Soviet Union, thus hindering the entire innovation process.

In the second step of the process, "preparatory measures," low-level efforts in a particular area continue, but they still yield to higher-priority programs. Evangelista credits the institution of new scientific research to evidence of similar technologies being developed abroad.[60] While the impetus may not be original, this stage of research is very important for Soviet scientists, preparing a technical background that will be useful once development of the technology is undertaken in earnest. The third stage of the process, "high-level response," builds upon this

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[56] Ibid., 30–49.

[57] Ibid., 52–53.

[58] Ibid., 69.

[59] Ibid., 53.

[60] Ibid., 1988.

research base to respond to foreign developments. This is a particularly important stage in Soviet innovation because it generally indicates the beginnings of a change in Soviet military priorities.

The final two steps, "mobilization" and "mass production," are similar processes on two different scales. In the first step, Soviet leadership typically endorses an all-out effort to pursue a particular innovation. The sheer amount of resources dedicated to the development of this process allows the system to overcome its typical inertia and make rapid advances in this area. However, speed of discovery does not equate to greater freedom for the scientists working on the problem. Military leadership retains a remarkable ability to "intervene in the process of carrying out an innovation," even choosing to end further development of a program after extensive testing. The final step in the process is the most public, as the government issues both policy statements and information about the new technology. This step also is indicative of the current priorities of the Russian military establishment. Any changes to the GS's priorities are formalized with these announcements and with the mass production and implementation of a new technology.[61]

As Evangelista moves through his discussion of the Soviet innovation process, the centralization of the Soviet system that prevents the scientists who are willing and able to innovate from doing so until large-scale structural changes can take place in the leadership's vision for the future is highlighted. Because innovation by scientists central to the success of the United States' military R&D program, this emerges as a crucial element. While the model itself appears to be applicable to the current Russian system for R&D, it seems as though scientists may gradually be gaining more of a voice in the government's allocation of funding for the development of various research programs. For example, in 2004, the Duma held hearings entitled "Nanotechnology—The Problems of Development and Training," part of which consisted of Nobel laureate Z. I. Alferov giving a report entitled "Nanostructures and Nanotechnology."[62] This is a small example of the kind of process that Evangelista celebrates in the United States, but it might, perhaps,

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[61] Ibid., 69–78.

[62] A. I. Terekhov, "Evaluating the Performance of Russia in the Research in Nanotechnology," *Journal of Nanoparticle Research*, 2012, 14 (11), 16.

provide fodder for a deeper analysis if more information can be found about this or similar incidents.

Both Adamsky's and Evangelista's explanations for Russia's current drive to improve its conventional weapons systems include nuances that account for the Russian government's inability to implement the MTR in a manner similar to that of the United States. Although these theories contend with a far different set of evidence to support their theories—a product of realism's unwillingness to open the "black box" of domestic politics—the final explanations of the Soviet government's behavior are logical outgrowths of both the historical events examined and of larger pressures governing the international system. The GS's unwillingness to expend large amounts of resources on the development of tactical nuclear weapons before the 1970s, for example, might suggest the competitiveness that Kaysen, McNamara, and Rathjens rely upon, but the examinations of the cultural factors at work within the Russian military in this culture of competition provide needed detail for unexpected behavior. Because both of these theories focus on past events, however, the applicability of these theories to the current innovation apparatus in the Russian Federation needs to be tested. While it retains elements of the Soviet government, the government of the Russian Federation is not precisely the same.

Slavo Radosevic's analysis of the Russian government's current attempts to spur innovation in its economy step into the gap left by theories of Soviet innovation by explaining the extent to which the Russian Federation's current policies are predicated on its past. Arguing that Russia is currently in the midst of an innovation crisis due to its desire to both restructure and preserve what remains of the Soviet innovation infrastructure, Radosevic argues that there are two major problems with continuing to employ this model in the future.[63] First, because the Soviet Union understood R&D as the main generator of technological innovation, other important aspects of the innovation process, such as "the role of users, engineers, and others not directly involved with R&D," were never considered.[64] As such, these avenues continue to be neglected by the current government. Second, the Soviet government perceived technology as a commodity that,

[63] Slavo Radosevic, "Patterns of Preservation, Restructuring, and Survival: Science and Technology in Russia in post-Soviet era," *Research Policy*, 2003, 32, 1106.

[64] Ibid., 1105.

once developed, "could be transferred into or introduced into production without need for continuous adaptations and improvements."[65] The latter is not only problematic for continuing to foster innovation within the scientific community, but also for the quality of Russian products meant to compete on the international stage. Although Radosevic lacks some of the rigorous development and details that Adamsky and Evangelista boast—due in large part to the fact that these ideas are in articles rather than in a book—his insights dovetail nicely with the conclusions of the two other authors and will aid in the analysis of current Russian innovation policies using the strategic cultural and five-step innovation models.

Legislation, Policy, and Organizational Structures

Because the Russian R&D apparatus remains highly centralized, the majority of prominent organizations encouraging innovation are tied to the government. The Russian government's current approach to innovation in many ways mirrors the process that took place in the Soviet Union. Just as the Soviet government funded the bulk of R&D activities through state-owned branch research institutes, Russia's current structure boasts a large network of research institutes that are largely separate from both industrial firms and the university system. These institutes, known collectively as the Russian Academy of Sciences (RAS), are more than thirty component organizations that publish independently and compete for state funding as individual entities.[66] Among the most prolific of these institutes are the Nesmeyanov Institute of Organoelement Compounds RAS, the Federal State Institution (FSI) Technical Institute for Superhard and Novel Carbon Materials, Lomonosov Moscow State University (MSU), the Institute of Microelectronics Technology and High Purity Materials (IMT) RAS, and the Landau Institute for Theoretic Physics (ITP) RAS. While similar institutions can be found throughout Asia, Western Europe, and the United States, the model under which Russia's current innovation initiatives is broadly and narrowly reminiscent of what existed under the Soviet Union. One hallmark of this model of development is the large gap that exists between the RAS research

[65] Ibid.

[66] "OECD Science, Technology, and Industry Outlook 2012," Organization for Economic Co-operation and Development, 2012, 368; and A. I. Terekhov, "Evaluating the Performance of Russia in the Research in Nanotechnology," *Journal of Nanoparticle Research*, 2012, 14 (11), article: 1250 3.

institutes and the university system.[67] As in the past, universities remain responsible for educating students without commensurate emphasis on research as is found in U.S. and western European research universities. As such, Russia's research institutes struggle to attract young minds to its research (even beyond the challenges of Russian demographic shifts of an aging population). This is problematic both because of the increasing need for competent young scientists to carry on the research of the aging scientific community and because it may prevent many of the mechanisms by which the Russian government hopes to stimulate economic growth in the scientific community from being sufficiently successful in the future.

Legislation enacted in the last several years provides evidence that some of the traditional government structures responsible for inciting innovation are beginning to be reformed, however. While still in the early stages, many of the Russian government's programs in this area seem to aim to increase growth in the private sector rather in particular. In 2005, the government passed a law incentivizing the creation of special economic zones (SEZs) to attract investment in manufacturing and "high-technology" development.[68] Incentives such as tax and customs breaks, financial guarantees, and "special credit conditions" are included in the bill for up to ten years as long as member corporations are willing to register with the government. After ten years, government incentives are lessened considerably in an attempt to ensure that startup corporations in these regions are able to function as competitive entities. The law also requires all member corporations—including multinational corporations (MNCs)—to submit to the same vetting process for residency in the SEZ and to apply for any grants made available to residents of the city. MNCs could thus be denied participation in the SEZ if their proposed projects fall outside the goals of the technopark associated with the SEZ. Although turning established corporations away seems counterintuitive, the government's oversight in this manner is one of a series of legislative necessities associated with successful SEZ.

A second component of successful SEZs was incorporated into Russian law in January 2008 when the Russian government passed the Federal Law on Science, which allows research

[67] Itzhak Goldberg, John G. Goddard, Samita Kuriakose, and Jean-Louis Racine, "Igniting Innovation: Rethinking the Role of Government in Emerging Europe and Central Asia," The World Bank, 2011, 83.

[68] Russian Federal Law "Об особых экономических зонах в Российской Федерации [About Special Economic Zones in Russian Federation]," 22 July 2005.

institutes and universities to share material resources, workforce, and facilities free of charge.[69] More importantly, the law allows universities and research institutes to form joint entities. Law 217 seeks to encourage further collaboration among universities and private industry by "encourag[ing] companies to establish partnerships with universities and get engaged in joint R&D activities and technological innovations.[70] Federal Government Directives 218-220 provide the legal authority for the collaborations to begin.

- Federal Government Decree 218, "The Federal Support of Cooperation Between Higher Education and High Tech Industry (April 9, 2010)," allocated $633 million between 2010 and 2012 for joint industry-university projects. Selected projects could be awarded up to $10 million according to three criteria: 1) that the project proposed by a research institution and company must require joint R&D at the research institution, 2) that the company will match the government grant with its own funding, and 3) that at least twenty percent of federal funding will be used for R&D.[71]

- Federal Government Decree 219, "Federal Support of the Innovation Infrastructure Development in the Higher Education Sector (April 9, 2010)," sought to support "innovation infrastructure development such as "business incubators, engineering centers, certification centers, transfer technology centers, information centers, and innovation consulting centers," as well as for entrepreneurial education and technology transfer consulting services.[72] All research institutions of higher education in Russia are eligible to compete for up to $1.7 million per year for three years.

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[69] Itzhak Goldberg, John G. Goddard, Samita Kuriakose, and Jean-Louis Racine, "Igniting Innovation: Rethinking the Role of Government in Emerging Europe and Central Asia," The World Bank, 2011, 96.

[70] Uvarov Alexander & Perevodchikov Evgeniy, "The Entrepreneurial University in Russia: from Idea to Reality," *Social and Behavioral Sciences*, 2012, 52, 47.

[71] Ibid.

[72] Ibid., 48.

- Federal Government Decree 220, "Support of Leading Scientists in the Higher Education Sector (April 9, 2010)," allocated $400 million from 2010 to 2012 to award grants to researchers that are renewable for up to two years. Researchers who were chosen to receive the funding must "form a team, establish a research lab, and make [a] contribution to his/her area of research."[73]

These joint entities are an important component of successful SEZs in both Western Europe and Asia because it allows for more flexibility in research. Furthermore, these collaborations allow universities and research institutes to become more responsive to the needs of the market, one of the biggest problems that the Soviet innovation system faced prior to its dissolution. For many years, the government's research demands usurped the market's, meaning that innovation occurred outside of the realm of citizens or investors' wants or needs. Increased collaboration between the research institutes and universities is meant to address this problem by providing the research institutes an arm that targets consumer needs specifically. Such changes are essential if Russia is to stimulate innovation in its economy and keep pace with other BRICS, whom it views as its largest competitors.

Just how important continued innovation is for the country was highlighted in a 2007 government document entitled the "Concept of the Long-term Socioeconomic Development of the Russian Federation."[74] Three potential outcomes for Russia are outlined if its efforts to incite innovation should fail. The first is the least appealing, outlining a scenario in which Russia continues to rely on "the resource export based model of development while the production of hydrocarbons gradually decreases."[75] According to this model, Russia becomes increasingly less competitive and, as such, income disparities between Russia and its neighbors grow. GDP growth is projected to fall to 3.5% by 2015 and will increase only a meager 1.6 times between

[73] Ibid., 49.

[74] "Kontseptsiia dolgosrochnovo sotsial 'no-ckonomicheskovo razvitiia Rossiiskoi Federatsii [The Concept of Long-term Socioeconmic Development of the Russian Federation]," The Ministry of Economic Development and Trade, Moscow, September 2007, 8–9.

[75] Andrew C. Kuchins, Amy Beavin, and Anna Bryndza, "Russia's 2020 Strategic Economic Goals and the Role of International Integration," Center for Strategic and International Studies, 2008, 4.

2008 and 2020.[76] The second scenario outlines the potential outcome of Russia improving the efficiency of its extracting techniques and power generation in order to maximize the productivity and growth in the energy sector.[77] Such a breakthrough allows for the "diversification in export destinations" and also provides the capital needed to modernize the country's transportation infrastructure.[78] Unfortunately, because this represents innovation in only one sector of the economy, the government still lacks the ability to provide for development and national security, placing it behind its peer competitors.[79] Lastly, the government presents its vision for "innovation-based development" that allows Russia "to broaden its comparative advantage beyond the sphere of energy and natural resources and to become a leader in technology as well."[80] Success in this endeavor allows standards of living to improve markedly as GDP per capita would rise to $21,000 by 2015 and to $30,000 by 2020.[81] Only in this model is Russia able to retain its standing on the world stage and its dominance in the region. This model and the many changes that it entails are presented as by far the best possible means of securing Russia's future.

In order to succeed in making the final vision a reality, a set of highly ambitious goals to promote innovation and economic growth in the country were outlined in the Ministry of Economic Development's "Innovation Strategy of the Russian Federation to 2020."[82] The strategy's objectives include: "further develop[ing] human capital, stimulat[ing] innovation activities in the business sector, creat[ing] a climate conducive to innovation in the public sector, increase[ing] efficiency and dynamism of R&D, and promot[ing] international STI co-

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[76] Kontseptsiia dolgosrochnovo sotsial "No-ckonomicheskovo razvitiia Rossiiskoi Federatsii [The Concept of Long term Socioeconmic Development of the Russian Federation]," The Ministry of Economic Development and Trade, Moscow, September 2007, 22–23.

[77] Ibid., 25.

[78] Ibid.

[79] Andrew C. Kuchins, Amy Beavin, and Anna Bryndza, "Russia's 2020 Strategic Economic Goals and the Role of International Integration," Center for Strategic and International Studies, 2008, 5.

[80] Kontseptsiia dolgosrochnovo sotsial "No-ckonomicheskovo razvitiia Rossiiskoi Federatsii [The Concept of Long-term Socioeconmic Development of the Russian Federation]," The Ministry of Economic Development and Trade, Moscow, September 2007, 26.

[81] Ibid., 26.

[82] "OECD Science, Technology, and Industry Outlook 2012" Organization for Economic Co-operation and Development, 2012, 368.

operation."[83] One such initiative is the State Programme for Development of Science and Technology for 2012-20, which has the stated goal of "develop[ing] a competitive and efficient sector of applied research and development."[84] This program provides public support for the advancement of priority technological advances and for S&T infrastructure that spanned multiple technological and business sectors. Support is also provided by a number of government agencies including the Ministry of Education and Science, the Ministry of Economic Development, the High Technology and Innovation Commission, the President's Commission for Modernisation and Technological Development of Russia's Economy.[85]

Even as these programs seek to stimulate the economy, however, the continued overwhelming reliance on the government as the driver of innovation harkens back to the Soviet apparatus. While some steps are being made to loosen the government's control over many of the major institutions within the innovation apparatus, the reality of the country's current economic state and population poses its own problems. While the Soviet Union was long regarded one of the leading countries in the number of highly educated individuals within its population—Russia still retains one of the best-educated populations in the world according to OECD data—strict divisions between the government, military, universities, and research institutes has led to a smaller number of science and engineering graduates over the years. Given President Putin's ambitious goals for improving the Russian economy by once again improving the scientific community's ability to innovate, the decreasing population of individuals qualified to take on these jobs may halt the project in its tracks if steps are not taken to reverse this trend. Secondly, the strong ties between the government and the research institutes mean that all employees are considered civil servants and that the resulting laws governing the firing of scientists and engineers currently employed in the research institutes are notoriously strict.[86] While this might have a positive impact on the work that scientists are able to carry out, it also makes replacing aging researchers very difficult. Researchers' civil servant status is also unappealing to many

[83] Ibid.

[84] Ibid.

[85] "Government Approves Framework Federal Targeted Research Programmes Until 2020," The Russian Government, 15 May 2013, par. 5.

[86] Itzhak Goldberg, John G. Goddard, Samita Kuriakose, and Jean-Louis Racine, "Igniting Innovation: Rethinking the Role of Government in Emerging Europe and Central Asia," The World Bank, 2011, 105.

individuals qualified to replace the aging resources due to the comparatively low salaries offered to government employees compared to their counterparts in the private sector. Lastly, the decreasing number of science and engineering graduates means that research institutes are hiring increasingly fewer staff with masters or doctoral degrees. As such, the quality of the work being released by these entities is likely to fall. Not only does this not portend well for the current joint ventures established in the wake of the 2008 law allowing collaboration, but it also calls into question their future sustainability. Both of these considerations could prove disastrous for the SEZs slated for development in the country, as the reputation of the corporations participating in these startups is a key measure of quality.[87] The possibility of investing in a collaboration that may or may not have the skilled personnel to carry on the projects in the future is not likely to attract much foreign investment, especially when technoparks, some more qualified and stable, and other SEZs are thriving in Asia.

Recent Russian Tech Development Programs

As mentioned above, Russia is in a transition period with regard to how it approaches technology development. While the government maintains a very active presence in the process of technology development, there has been an increasing movement toward decentralization in recent years. The decentralization programs proposed thus far, however, retain a distinctly Russian sensibility in that decentralization is meant to occur with huge outlays of government funding. One such initiative is the State Programme for the Development of Science and Technology for 2020, which was passed in December 2012.[88] Although this program shares a name with a similar program that ended in 2013, this bill visualizes Russian science and technology taking on a very different role in the future Russian economy. Rather than seeking to simply "recover and sustain the scientific and technological potential of the country," the program allocates 145.12 billion rubles ($3.6 billion USD, at the time) "to make science and

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[87] J.Q. Trelewicz, "An Analysis of Technology Entrepreneurship in the Modern Russian Economy exploring SEZ, Technoparks, and the Skolkovo Program," *IEEE International Technology Management Conference*, 2012, 290.

[88] "The Government Programme 'Development of Science and Technology in 2013–2020,'" *ERAWATCH*, 25 February 2013, par. 8.

technology a driving force of the economy."[89] In order to make Russian science competitive with similar programs around the world, several key areas that would ensure efficient use of resources are addressed in the document. These include the imbalance between the supply and demand of R&D goods that is exacerbated by the insufficient effectiveness of basic science and research; the lack of interest and weak participation of the business sector in R&D; the generation gap (high average age of researchers) in the sector; the competitiveness of the working conditions for scientist and researchers; the poor integration of the Russian R&D sector into the international R&D sector; and the obsolescence of the resource base for the R&D sector.[90]

In order to address the wide range of identified issues, the program encapsulates six subsidiary programs and three "Federal Targeted Programmes." The sub-programs include: "Basic research;" "Pre-discovery and applied problem-oriented research and laying scientific and technological foundation in the sphere of leading edge technology;" "Development of research institutions;" "Development of inter-disciplinary structure of the R&D sector;" "International scientific cooperation;" and an administrative program.[91] The program will be implemented over three stages, the first set to begin in 2013 with the improvement of the state science funding and regulation and the clarification of the program itself. The second phase spans from 2014–2017 and "aims to increase the quality of work of the research institutions, make salaries in the sector more competitive, introduce new form (sic) of support of individual R&D work (grants), and construct mega-science installations."[92] The last phase will span 2018–2020 and will focus on sustaining the gains made in the previous two phases. Although the government remains a major part of this initiative, the program, as currently written, relies heavily on competitive funding mechanisms to allocate funds to "public and private research institutions, education institutions and scientific centres, as well as to individual researchers and PhDs."[93]

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[89] "Russian Government Programme 'Science and Technology Development in 2013–2020,'" *EAST*, 04 March 2013, par. 2.

[90] "The Government Programme 'Development of Science and Technology in 2013–2020,'" *ERAWATCH*, 25 February 2013, par. 8.

[91] Ibid., par. 12.

[92] Ibid., par. 29.

[93] Ibid., par. 30.

The information technology (IT) industry is one in which the Russian government may most quickly see a return on its investment. Although still a very small sector of the economy—it employed only 0.6% of the Russian workforce in 2012—it garnered 1.2% of the GDP.[94] What truly differentiates the IT industry from other branches of Russian governmental innovation is that the average age of the workers in that sector is much younger than that of the sciences—averaging thirty years of age while the average Russian scientist is 53 years old.[95] The Russian government's attempts to encourage innovation in this area are equally varied. Although the government has attempted to spur growth in this area in the past, the great potential for growth in this sector has precipitated a particularly strong drive among government officials to see this sector grow. In order to do so, President Putin has begun a process that includes the hallmarks of the Russian innovation process while also providing insight into the direction future Russian efforts to innovate may take. The following case study will examine this process in detail.

Skolkovo: A Window to Russia's Future?

In 2010, the Russian Duma approved a proposal to allocate more than $4 billion (in USD at the time) to Skolkovo, a three-pronged approach to encouraging innovation that includes a high-tech "innovation city" meant to serve as Russia's answer to Shenzhen in China and India's largest technopark in Thiruvananthapuram (Trivandrum), Kerala; a business incubator for entrepreneurs in the technology and applied research sectors (the Skolkovo Foundation); and a "world class technology university, Skolkovo Institute of Technology (SKTech)."[96] Each of the three parts of the effort is intended to perform a role in the innovation process while also working collaboratively with the others to draw both domestic and international investors. Since construction of the project began, members of the Russian government touted the project as the "Russian Silicon Valley."[97] Viktor Vekselberg, the Skolkovo Foundation president, predicts that

94 "Meeting of the Presidium of the Presidential Council for Economic Modernization and Innovative Development," The Government of the Russian Federation, 24 December 2012, par. 18.

95 Ibid., par. 19; A. I. Terekhov, "Evaluating the performance of Russia in the research in nanotechnology," *Journal of Nanoparticle Research*, 2012, 14 (11), article: 1250 3.

96 J.Q. Trelewicz, "An Analysis of Technology Entrepreneurship in the Modern Russian Economy exploring SEZ, Technoparks, and the Skolkovo Program," *IEEE International Technology Management Conference*, 2012, 288.

97 Rebecca Grant, "Russia Investing $4 B in 'Innovation City' Skolkovo to Inseminate Start up Culture," *venturebeat*, 9 August 2013, par. 2.

the city will raise $11 billion through private investors by 2020 and that it will add up to $45 billion to national GDP.[98]

How will the city achieve such spectacular growth? The challenge is significant and relies on acquiring just the right balance of technology startups and established companies taking up residence in the technopark. A widely cited estimate of this ratio is drawn from Finland's successful technoparks: 94% of residents in a technopark should be established and only 6% true technology startups.[99] After appropriate companies are identified and given permission to take part in a technopark, resident companies then research and develop products that can find a commercial audience and give a portion of their profits on these technologies in rent and taxes.[100] Ideally, the success of the first companies to take up residence in a particular technopark would then attract new and more profitable companies or investment in the companies already in residence. In this way, developments in the technoparks would be absorbed into the Russian GDP and provide a much-needed boost to the country's economic growth.

In the majority of the successful technoparks, resident businesses are initially granted special tax incentives or other comparable benefits in exchange for becoming a resident company. Ideally, however, this government assistance is eventually discontinued because the technopark is self-sufficient. Determining the exact point at which a government should begin removing incentives from a technopark is far less straightforward than it might seem, however. A recent IEEE Technology Management Conference considered this issue and reached only the tentative conclusion that while too much focus on the tenants' research and commercial success can prove detrimental to efforts to build the park's reputation, providing too much state assistance to residents can turn an avenue for private sector innovation into "a model for distributing state support."[101] The former model can place too much emphasis on the results of investment—potentially scaring residents away—while the latter can impede any transition to self-sufficiency.

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[98] Ibid., par. 3.

[99] J.Q. Trelewicz, "An Analysis of Technology Entrepreneurship in the Modern Russian Economy exploring SEZ, Technoparks, and the Skolkovo Program," *IEEE International Technology Management Conference*, 2012, 289.

[100] Ibid., 290.

[101] Ibid.

On paper, the 2005 SEZ act seems to strike a reasonable balance between the two extremes. While the Skolkovo program has received a large amount of government seed money, the benefits to residential companies expire after a decade. Although the technopark is in its early stages, this provides a definite point at which the self-sufficiency of the resident companies is expected. Currently, the law also holds both established corporations and technology startups to the same process of government review to ensure that their research is beneficial for Russian consumers and that the money being given to the corporation is used wisely. Although such measures may seem extreme to established companies, the review process is one way of monitoring the government's investment and of ensuring that the R&D occurring is focused on the creation of new technology rather than simply transferring existing technology to Russia. International investors are beginning to respond to the program. In August 2012, the Massachusetts Institute of Technology (MIT) agreed to partner with the SKTech and work alongside prominent Russian universities, including Lomonosov Moscow State University, to create a more innovative atmosphere while drawing on the considerable scientific knowledge of the partner universities.[102]

As with most aspects of innovation in Russia, however, the government retains strong ties to the project, providing both the seed money to begin construction and also helping to appoint the leaders of the Technopark, Skolkovo Foundation, and the Skolkovo Institute of Technology. Such close ties call the self-sustainability and independence of the program into question. This significant government involvement with the leadership of the program is similar to projects that undertaken during the 1950s and 60s under the Soviet government. In 1957, the government established Akademgorodok—literally "academic town"—a "science city" that included research institutes, a university, housing, entertainment, stores, and other resources for its citizens. Similar cities were built near Tomsk in 1972, and a town known as Zelenograd was "repurposed from a manufacturing to a high technology city in 1962."[103] Given the Soviet government's propensity for involvement in all major projects, it is likely that government officials held the positions of authority within the commercial and research portions of the science cities. The question

[102] Ibid., 291.

[103] Ibid., 290.

therefore becomes to what extent is the current Russian model of innovation in this area different from that of the Soviet Union?

Applying Evangelista's five-step process for Soviet innovation to this question reveals surprising similarities between the two innovation systems. While step one, "stifled initiative," seems to be corrected by the principles underlining the creation of all three prongs of Skolkovo, the concept underlying the second step, "preparatory measures," has more resonance. While the Skolkovo program is a very large, public display of the government's commitment to innovation in the private sector, the five year gap between the passage of the 2005 SEZ law and the passage of the bill creating the Skolkovo program could indicate low-level support for the idea within the government. Large projects require time to draft, but five years seems quite long given the magnitude of success that similar SEZs have achieved in the other BRICS countries. Therefore, the lag may indicate hesitancy or a general lack of interest on the part of government leaders.

The third step, "high-level response," obviously occurred in this process as evidenced both by the passage of the law and the subsequent government support, both monetary and verbally in a variety of high-profile speeches and conferences. What is unclear about this step, however, is whether the push by government officials truly occurred in response to perceived change by peer states. Successful SEZs have been a large part of the global economy for many years, especially in Asia. If the government decided to make Skolkovo a priority in response to success in areas such as Shenzhen, the program took a longer time to pass than would be expected by the model. Evangelista's understanding of this step indicates a fairly rapid response to innovations by other countries, but the five-year gap in the Skolkovo process indicates something else may be a driving factor. Even taking into consideration the global recession that occurred in 2008, the gap seems unusually long.

Because of the size and singular nature of the Skolkovo project, it is difficult to tell if any "mobilization" process occurred, or if the concept of "mass production" is more applicable to the current rollout of the program. Voting to fund the creation of such a large program, in addition to the repeated statements on the part of government leaders indicate that a hybrid of the two steps may provide the most comprehensive explanation of the process. For Evangelista, the mobilization process is marked by an all-out government effort to support the creation of a needed product. Such support is clearly evidenced here; however, the very public nature of the manner in which the program was created—through the passage of a bill in the Duma—also provides evidence for the public statements about a given government policy toward new technology that are the hallmark of mass production.

Using Evangelista's model as a template for exploring the development of the Skolkovo program indicates a large amount of overlap between the current innovation process and that which occurred under the Soviet Union. This is not to say that no differences exist between the two—the very nature of the Skolkovo program and its emphasis on private sector innovation differs substantively from the Soviet model. Nonetheless, it is important to recognize that the Russian government's ambitious plans for scientific innovation may be foiled by this close resemblance, organizational structure fidelity, and predominance of older individuals.

Such a resemblance is only intensified by a variety of scandals associated with the Skolkovo Foundation recently. In February 2013, the Russian Investigative Committee filed criminal charges against Kirill Lugovtsev, the Finance Department Director at the Development Foundation of the Center for Development and Commercialization of New Technology (the Skolkovo Foundation) for the embezzlement of 24 million rubles ($800,000 USD at the time). The charges followed the revelation of "materials from the Audit Chamber and the Federal Security Service."[104] Charges were still pending even as then-Prime Minister Dmitry Medvedev announced on August 1, 2013 that Skolkovo would receive another 100 billion rubles of foreign investment in the next eight years.[105] The success or failure of the government in this sector could have huge repercussions for Russia's future economic growth, but it appears as though hallmarks of Soviet enterprises such as corruption may be a substantial hurdle in Russia's plans for its future.

104 "Two Skolkovo Managers Suspected of Stealing $ 800 Thousand," *Russia Beyond the Headlines*, 12 February 2013, par. 3.

105 "Skolkovo Will Get over 100 Billion Rubles of Non-State Funds in the Next Eight Years- Medvedev," *Russia Beyond the Headlines*, 1 August 2013.

Part III. Codifying Nanotechnology Variables

Moving beyond the historical frameworks, a set of variables that would inform the international security implications of emerging technologies and specifically nanotechnology were sought. Initially, a set of twelve variables was proposed based on analysis of historical and current programs, as well as review and analysis of federally funded nanotechnology programs in the United States related to national defense. These programs were identified through participation in the annual Nanotechnology for Defense (NT4D) conferences from 2008–2012. The set of variables was later reduced to eight. The following variables were identified as significant in influencing the development of and driving missions of the nanotech programs in the United States:

1. Dual-Use Nature of Nanotechnology: Offensive vs. Defensive Capabilities
2. Nanotechnology and RMA: Disruptive (Revolutionary) vs. Sustaining (Evolutionary) Technology
3. Maturity of the Nanotech Industry: Institutionalized vs. Transitory Programs
4. Origin of Technology: Private vs. Public Investment
5. Institutions: Capacity and Collaboration
6. Research and Development of Nanotechnology: Overt vs. Covert
7. Technological Imperative: Tech Driven vs. Tech Pulled
8. Regulation of Nanotechnology: National vs. International Regulatory Framework

For each variable framework, the report will include analysis of:

i. Variable Significance
ii. IR Theoretical Framework
iii. Metrics for Assessment and Proposed Assessment Type
iv. Preliminary Findings
v. Areas for Continued Research

We are currently in the process of testing the variables and doing a semi-empirical analysis against data from the 2013 and 2014 NT4D conferences. Across all the variables, a score from 0 to 10 for each variable will allow a single cumulative score to be calculated for a technology or program. A high cumulative score is expected to indicate that a technology is offensive, disruptive, institutionalized, privately funded, covert, technologically driven, and regulated by a highly restrictive framework. Scores of 5 on all scales indicate that a technology is neutral on that measure.

1. Dual-Use Nature of Nanotechnology: Offensive vs. Defensive Capabilities

Significance

As global interest surrounding nanotechnology continues to grow in both the public and private sphere, nations will increasingly seek out both commercial and military applications of such emerging technology. The ubiquitous nature of nanotechnology—along with biotechnology and information and communications technologies—means that its applications are likely to be far reaching. Understanding potential proliferation challenges and threats that may be wielded through application of these technologies is critical.[106] Former Vice Chairman of the Joint Chiefs of Staff Admiral (Ret.) David E. Jeremiah underscored the necessity of analyzing the militarization of innovations achieved in nanotechnology: "Military applications of molecular manufacturing have even greater potential than nuclear weapons to radically change the balance of power."[107] It is the unique dual-use nature of innovations in nanotechnology that will drive advancements in both offensive and defensive capabilities; in a scenario in which a state heavily pursues offensive nanotechnology, aggression and conflict are more likely to ensue. However, the militarization of advancements made in nanotechnology may not be easily distinguishable as either a defensive or offensive capability. This inherent uncertainty will require nations to interpret and then react accordingly to adversary and ally nations' advancements in nanotechnology. This leaves the door open for nations to misinterpret capabilities as defensive, offensive, or a combination of both, resulting in a security environment at the mercy of an actor's perceptions. Perhaps more importantly, the incentive will be to hedge and assume that applications are offensive in the face of substantial technical, operational, and strategic

[106] Margaret E. Kosal, "The Security Implications of Nanotechnology," *Bulletin of the Atomic Scientists*, July/August 2010, 67–74.

[107] David E. Jeremiah, "Nanotechnology and Global Security," Palo Alto, CA; Fourth Foresight Conference on Molecular Nanotechnology, 1995.

uncertainty. When technological change is perceived to further offensive capabilities, this "exacerbates the security dilemma among states, intensify arms races, and make wars of expansion, prevention, and preemption more likely."[108]

IR Theoretical Framework

The most general prediction of offense-defense theory is that international conflict and war are more likely when offense has the advantage, while peace and cooperation are more probable when defense has the advantage. Offense-defense theory share the basic assumptions of structural realism: states seek to maximize their security by pursuing their self-interests, and ultimately their survival, in an anarchic system. However, the offense-defense power theory offers an explanation of the relationship between power (resources) and threats. When the balance favors the defense, resources are more easily used to counter threats rather than to threaten, while if the balance favors the offense, resources are more easily used to threaten rather than to counter threats.[109] This balance is shaped by a state's existing amount of resources, specifically the existing pool of available technology. Innovation in technology can impact this available pool of technology in two ways: the first is innovations that produce weapons that result in increased capability at lower costs and the second is commercial technological innovations that result in lower production costs of weapons and/or weapon systems.[110] Such technological advances and resulting efficiencies in cost and performance facilitate states adopting offensive strategies and capabilities which, as previously stated, will serve to exacerbate the security dilemma among nations.

Metrics for Assessment and Proposed Assessment Type

When analyzing the impact of innovations in nanotechnology, the resulting military applications, including novel weapons as well as the expansion of existing capabilities, can be measured in the

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[108] Keir A. Lieber, "Grasping the Technological Peace: The Offense-Defense Balance and International Security," *International Security*, Summer 2000, 71–104.

[109] Sean M. Lynn-Jones, "Does Offense-Defense Theory Have a Future?" Montreal: Research Group in International Security, 2001, 14.

[110] Ibid., 18.

context of the offense defense balance by understanding the relationship between the attacker and the defender as a cost ratio that, when balanced, is equal to one. Utilizing the method proposed by Glaser and Kaufmann:[111]

$$R = C_a / C_d$$

if the cost to the attacker (C_a) is greater than the cost associated with the defender (C_d) then the defense is favored (R>1). If the cost of the defense (C_d) is greater than the cost of the offense (C_a) then it is in favor of the offense (R<1).[112] By adopting Glaser and Kaufmann's method of measurement of the offense-defense theory to analyze the effect of military applications of nanotechnology, the cost ratio between the attacker and the defender can still be utilized. The means to determining the actual ratio R will result from a qualitative analysis of a specific military application of nanotechnology and how it impacts the capability/resource set of both the offense and the defense. Upon determining the value of R, a dummy variable could be created that will convert R into a categorical or nominal variable:

- R < 1, R=1, 1 = offense
- R > 1, R=2, 2 = defense
- R=1, R=3, 2 = dual

Preliminary Findings

The United States Department of Defense (DOD) proposed $289.4 million USD budget for nanotech specific research and development in 2013. The proposed DOD nanotech budget is broken down into eight program component areas as shown in **Table 1**.

[111] Charles Glaser and Chaim Kaufmann, "What is the Offense-Defense Balance and Can We Measure It?" *International Security*, Spring 1998.

[112] Ibid.

Table 1: 2013 Proposed DOD Investments by Program Component Area (millions USD) [113]	
1. Fundamental Phenomena & Processes	138
2. Nano-materials	32.7
3. Nano-scale Devices and Systems	95.6
4. Instrument Research, Metrology & Standards	1
5. Nano-manufacturing	6.2
6. Major Research Facilities & Instr. Acquisition	15
7. Environment, Health, and Safety	1
8. Education & Social Dimensions	0
NNI Total	$289.4 M

Although no data specifically regarding Russian military spending as it pertains to research and development of nanotechnology was identified during this project, statements made by political and military elites have underscored Russia's intent to invest heavily in potential military applications of nanotechnology. One such statement was made by then-President Medvedev during a speech to the Moscow International Nanotechnology Forum, indicating the perceived value of advanced technologies and challenges in October 2009: "what we really need is the transfer of high technologies and their adaptation to Russian industries … this is the most difficult challenge, and so far in this regard we have had very little success."[114] Russia's current inability to develop innovative nanotechnology is endemic to its military development efforts in advanced technology as well. According to one Russian defense analyst, the Russian defense industry has "lost… many of its most important technologies" and begun to "lag behind the west in communications, reconnaissance, navigation, observation, EW [electronic warfare] and

[113] Subcommittee on Nanoscale Science, Engineering, and Technology Committee on Technology National Science and Technology Council, "The National Nanotechnology Initiative: Supplement to the President's 2013 Budget."

[114] "Russia: Medvedev Addresses Opening of Moscow International Nanotechnology Forum, President of Russia—Official Website of the Russian Federation President," 7 October 2009, OSCE Translated Excerpt via World News Connection. Cited in Andrew Wallace, "Russia's Military Industrial Complex Struggles to Modernize," *The ISCIP Analyst*, 15 October 2009, 16:3, http://www.bu.edu/iscip/digest/vol16/ed1603a.shtml.

control systems."[115] These ideas were re-affirmed in statements by former First Deputy Defense Minister Vladimir Popovkin, who had risen to the rank of general in the Soviet and Russian Space Forces, who acknowledged that the Russian "Defense Ministry is forced to purchase technologies abroad because Russia's electronics industry is incapable of manufacturing all necessary parts and microcircuits for weapon production."[116]

Given the highly secretive nature of the Russian military, it is difficult to find any information about either current military R&D or the future uses that the Russian military envisions for nanotechnology. What is clear, however, is Russian government officials' beliefs in the potential for nanotechnology to transform their current weapons systems. President Putin's annual address to the Duma in 2007 provided an indication of just how important nanotechnology is for the future of the country. Specifically, he announced the creation of a $7 billion project specifically to enhance the development of nanotechnology in Russia, an amount of money that was unprecedented.[117] In fact, the size of the investment means that nanotechnology would receive "three times more state funding than the rest of the Russian scientists put together."[118] It is impossible to know precisely how much of this money is allocated specifically for military R&D and how much will be put toward Putin's ambitious plans to revive private investment in scientific development across all sectors of the economy, but statements by various Russian politicians indicate that they are very much aware of nanotechnology's potential to revolutionize their military. Ivanov, for example, stated, "nanotechnology could not only change our whole economy and the quality of life for the Russian people but could also drastically change all perceptions about modern warfare."[119]

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115 "Russian Expert Supports Weapons Imports for Armed Forces, *Nezavisimaya gazeta,* 18 August 09. Cited in Andrew Wallace, "Russia's Military Industrial Complex Struggles to Modernize," *The ISCIP Analyst*, 15 October 2009, 16:3,

116 "Russia: No Iskanders Deployed in Kaliningrad Oblast for No BMD in Eastern Europe, *Vzglyad*, 21 September 2009; OSCE Translated Excerpt via World News Connection. Cited in Andrew Wallace, "Russia's Military Industrial Complex Struggles to Modernize," *The ISCIP Analyst*, 15 October 2009, 16:3.

117 Jason Bush, "Russia bids to become a tiger," *Business Weekly Online*, 27 June 2007.

118 Ibid.

119 Keri Smith, "Russia Keeps Watch on New Holdings' R & D Spend," *Jane's Defence Weekly*, 30 May 2007, no. 22, 44.

A particularly interesting piece, published recently by *BBC Worldwide Monitoring* on December 3, 2013, provides an uncharacteristically clear picture of the direction the Russian government seeks to take its nanotechnology program. The article is a translation of remarks by the Russian Deputy Premier Dmitry Rogozin's November 22 speech entitled "Sixth Generation Technologies Will Make It Possible to Print Weapons on Special Printers and to Grow 'Spare Parts' for Humans."[120] Rogozin explains in his speech the intersection of two key points: first, that sixth generation technologies—which he claims began in the 2010s—will allow technologies that once seemed like science fiction to become reality, and second, that Russia is in a unique position to avoid the United States' current technological barrier in developing these technologies. Specifically, Rogozin argues that the current gap between the United States' research in sixth generation technologies and Russia's current research may help Russia avoid some of the lags in development. As the United States continues to work through the barriers to innovation in these technologies, Russia can continue to advance its current research and development efforts. By the time Russian research advances to the current level of the United States, the technological challenges may be circumvented or solved.

As such, Rogozin posits that Russia can catapult over some of the stages of technological development that countries on the cutting edge of research in sixth generation technologies have endured. Rather than simply invest in emerging Russian nanotechnology firms, RusNano has actively purchased large shares of established corporations in other states. Not only do such acquisitions lend some stability to RusNano's portfolio, but they also allow Russian nanotechnology to benefit from their continued innovation without waiting for earlier stages of development to be met. RusNano's recent acquisition of two bioscience firms, BIND and Selecta, required the firms to establish subsidiaries in Russia and to "conduct full-cycle drug development—from R&D through manufacturing and commercialization."[121] Despite fostering growth in these areas, "the depressed state of the economy and turbulence in the financial markets is blocking the normal operation of marketing mechanisms of the reproduction of

120 "Russian Deputy Premier Notes Need for Technological Progress," *BBC Monitoring Former Soviet Union-Supplied by BBC Worldwide Monitoring*, 3 December 2013, par. 10.

121 "RusNano Invests in Selecta Biosciences and BIND Biosciences to Develop and Commercialize Cancer Drugs in Russia," *nanowerk*, 27 October 2011, par. 3.

financial, physical, and human capital."[122] Even as he glosses over the current state of Russian innovation in these technologies, Rogozin is careful to point out the risk inherent in attempting to improve the Russian economy through intense focus in only one sector. Such research is imperative not only because of the potential economic implications of success but also to maintain an acceptable military-strategic balance with the United States, the European Union, and Japan.[123]

Although the speech does not provide specific examples of research in nanotechnology or other sixth generation technologies, the speech provides an important window into the rhetoric surrounding the development of nanotechnology in Russia, and also into the current state of research. While the Russian government clearly understands the depth of potential uses for these technologies, it does not currently have the capacity needed to compete with on the leading edge. Publicly acknowledging its intention to fund high-risk research and to stir investors' interest in "pre-venture funding" indicates what some Western watchers have speculated for years: that RusNano, while heavily funded, is far less successful than the government acknowledges. As such, it is unlikely that Russian nanotechnology research will move beyond basic research in the near future.

Specific examples of Russian research into nanotechnology are most often found in press releases. In the last year, *Pravda* reported on breakthroughs in a nano-enabled oral vaccine for hepatitis B, and Putin's announcement of a new Russian-Kazakhstani Nanotechnology Venture Fund created to "encourage innovation cooperation."[124] Interestingly, the most specific coverage of potential military applications of Russian nanotechnology is found in the Iranian media. In the last five years, the *FARS News Agency* published articles outlining the specific properties of removing atherosclerotic plaque by combining adult stem cells with nanoparticles and of ceramic nano-armor for the military and police by the end of 2015.[125]

122 "Russian Deputy Premier Notes Need for Technological Progress," *BBC Monitoring Former Soviet Union-Supplied by BBC Worldwide Monitoring*, 3 December 2013, par. 10.

123 Ibid.

124 "Hepatitis B: Breakthrough!" *Pravda*, 13 November 2012; Olivia Kroth, "Twenty Years of Russian-Kazakh Friendship," *Pravda*, 6 December 2012.

125 "Nanoparticles Plus Adult Stem Cells Demolish Atherosclerotic Plaque," *FARS News Agency*, 22 July 2010; "Russian Military to Receive Nano-Armor by 2015," *FARS News Agency* 13 August 2013.

U.S. military predictions also provide a window into the potential future of Russian military capabilities if Russia's large outlay of funding for nanotechnology proves successful. In many cases, discerning U.S. rhetoric from technical reality is as challenging as it is for the case of Russia. For example, it has been predicted that the current Russian nanotechnology program may soon lead to the development of miniaturized control and power systems that could provide the foundation for "massive numbers of inexpensive unmanned aerial vehicles (UAV) capable of delivering biotech-engineered weapons."[126] It is hypothesized that such weapons could become especially important to the Russian military if Putin's restructuring of the economy results in either the second or third scenario outlined in the *2020 Concept*. Should Russia sufficiently enhance the efficiency of its energy sector, for example, UAVs might serve an important role in helping to protect its resources and the infrastructure that helps deliver those resources to the market. Some U.S. observers indicate that in this scenario Russia's ability to project its authority using conventional weapons will extend only to the "near abroad" (i.e., eastern Europe, the Caucuses, and central Asia). In such a scenario, Russia would come to rely heavily on UAVs and other aircraft to aid in intelligence, surveillance and reconnaissance (ISR) and conduct near-autonomous operations.[127] As such, it is likely that Russia's near-to-middle-term goals would focus primarily on defensive weapons that are smaller and more autonomous with the addition of nanotechnology. Whether or not this is true needs more study. Even with a large population of scientists and researchers and an obvious commitment, the technology necessary to begin to create purely offensive weapons using nanotechnology may not exist until much later.

Continued Research

Analysis of potential military applications of nanotechnology needs to consider the likelihood of specific strategic, operational, and tactical uses of nanotechnology. There is a need for robust technical cases studies that combine such knowledge with the consideration of motivation and intent that will drive the military capability. Such case studies will also help disaggregate whether something is intended for offensive or defensive purposes, or perhaps even dual usage.

[126] Theodore C. Hailes et. al. "Resurgent Russia in 2030: Challenges for the USAF," Center for Strategy and Technology, Air War College, September 2009, 64.

[127] Ibid., 65.

In addition, although funding data was available for DOD-proposed investment in nanotechnology broken down by program component area, any comparable Russian military nanotechnology funding data was not available.

2. Nanotechnology and RMA: Disruptive vs. Sustaining Technology

Variable Significance

The Department of Defense's Office of Net Assessment originally defined a revolution in military affairs (RMA) as "a major change in the nature of warfare brought about by the innovative application of technologies which, combined with dramatic changes in military doctrine and operational concepts, fundamentally alters the character and conduct of operations."[128] Are advancements in nanotechnology evidence of an evolutionary outgrowth of a new capability or are they in fact a key driver of a new RMA? Is nanotechnology a revolutionary technology that will ultimately induce "a fundamental change in who, how, and, perhaps even why wars are fought?"[129] If nanotechnology emerges as a disruptive innovation, a new market, as well as a new value network, will emerge and ultimately serve to replace existing markets and value networks.[130] Advancements in nanotechnology, as an example of disruptive technology, would result in novel capabilities that have the potential to fundamentally change the current warfighting environment through the introduction of new offensive as well as defensive technologies. By understanding advancements in nanotechnology as an example of an emerging disruptive technology, the extent of future military applications is virtually limitless. However, if advancements in nanotechnology result in the evolution of existing military capabilities, the benefits as well as consequence of new nano-weapons and warfighting capabilities may be as unprecedented as the introduction of novel warfighting capabilities that would emerge through disruptive innovation.

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128 Earl H. Tilford, "The Revolution in Military Affairs: Prospects and Cautions," U.S. Army War College's Strategic Studies Institute, June 1995.

129 Ibid.

130 Joseph L. Bower and Clayton M. Christensen, "Disruptive Technologies: Catching the Wave," *Harvard Business Review*, January 1995.

A disruptive technology, by definition, is a technological advancement that drives political and societal changes. Although pundits and scholars, along with a few scientists, hypothesize that nanotechnology may in fact provide the changes to society and to warfare necessary for it to be considered a truly disruptive technology, current deployments of nanotechnology indicate that this may not be the case—or at least, not for a very long time. The U.S. National Nanotechnology Initiative (NNI) provides a list of potential innovations in defense technologies that nanotechnology may allow in the future, including: information dominance through nanoelectrics; virtual reality systems for training; automation and robotics to offset reductions in manpower, reduce risks to troops, and improve vehicle performance; higher-performance platforms with diminished failure rates and lower costs; improvements in chemical/biological/nuclear sensing and casualty care; improvements in systems for non-proliferation monitoring; and nano/micromechanical devices for control of nuclear weapons.[131]

While some are still in the basic research stage, many of these technologies may indeed prove to be disruptive when they become a reality. Utilizing robots to augment human soldiers on the battlefield, for example, necessitates a variety of changes to current understandings of troop movement, operations, and strategy on the battlefield. Similarly, nanoelectrics could allow militaries access to enemies' computer networks in ways that are unforeseen in the world of cybersecurity today, creating new threats for government and private industrial sectors. Both of these technologies have the potential to revolutionize aspects of civilian life as well. Before robots could be trusted on the battlefield, it is conceivable that they would need to prove reliable in other roles including, perhaps, as domestic aids for the elderly. Nanoelectrics' potential to revolutionize cybersecurity is perhaps even more disruptive, as it impacts the military, government, independent businesses, and individual citizens every day. Should changes to cybersecurity become as severe as Roco and Bainbridge claim, it would undoubtedly necessitate a government response in the form of new laws or protections.

[131] Mihail C. Roco and William S. Bainbridge, *Societal Implications of Nanoscience and Nanotechnology*, Boston: Kluwer, 10–11.

IR Theoretical Framework

If nanotechnology is understood to be a "disruptive technology," then by definition technological advances will ultimately drive political and societal changes. Disruptive technology within the military can be understood through examining the concept of revolution in military affairs (RMA). Nikolai Ogarkov's writings on the Soviet military during the 1970s and 1980s examined the potential revolutionary impact of new military technologies, resulting in what was once referred to as the military-technical revolution, an idea that has evolved into today's concept of an RMA.[132] Such technological innovation will drive change in existing military technology and capabilities, organizational and system structure, and operational innovation. Today there are two broad schools of thought about RMA. The first school, developed by Admiral William Owens, is known as "systems of systems;" proponents of the "systems of systems" theory believe that warfare will be dominated not by individual weapons but by real-time data processing, successful integration of capabilities, and information dissemination.[133] The second school of today's RMA debate is known as the "vulnerability" school. Proponents of the "vulnerability" school argue that the greatest threats posed to the U.S. military are and will continue to be those posed by the vulnerabilities of both defensive and offensive systems, including vulnerability to enemy cruise, anti-ship, and ballistic missiles; anti-satellite systems; and enemy intrusion into and extraction from communication systems.[134] Underpinning both schools of thought is that at the core of an RMA are technology and the disruptive capabilities that it enables for achieving a desired strategic end state.

If technology is in fact at the core of a revolution in military affairs, then it is important to understand how revolutions in technology have the ability to influence or shape society. Nanotechnology proponents are often noted for underscoring how future advancements in nanotechnology will reshape the world and society as we know it.

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[132] Steven Metz and James Kievit, "Strategy and the Revolution in Military Affairs: From Theory to Policy," U.S. Army War College Strategic Studies Institute, June 1995.

[133] Andrew Richter, "Lessons From the Revolution: What Recent U.S. Military Operations Reveal About the Revolution in Military Affairs and Future Combat," *Journal of Military and Strategic Studies,* Spring 2005, 4.

[134] Ibid., 5.

Metrics for Assessment and Proposed Assessment Type

In order to measure the extent to which advancements in nanotechnology are in fact driving a technological revolution, a qualitative analysis must be conducted. One possible method is to utilize Carlota Perez's techno-economic paradigm. Perez defines a technological revolution (TR) as a "major upheaval of the wealth-creating potential of the economy, opening a vast innovation opportunity space and providing a new set of associated generic technologies, infrastructures and organizational principles that can significantly increase the efficiency and effectiveness of all industries and activities."[135] Utilizing this definition, the industries that emerge from the corresponding TRs and the resulting novel infrastructures are binned into one of five technological revolutions. The five technological revolution as outlined by Perez include: the Industrial Revolution; Age of Steam and Railways; Age of Steel, Electricity, and Heavy Engineering; Age of Oil, the Automobile, and Mass Production; and the Age of Information and Telecommunications.[136] Through employing this qualitative framework, it is possible to expand upon the qualitative study conducted by Perez and analyze the extent to which nanotechnology is and/or will be categorized as the "sixth" revolution in technology and therefore an example of a disruptive technology.

It is unclear, particularly in the case of a "late, late innovator" like Russia, whether the current model the government is employing will allow Russia to benefit from the advancements in military technology in a significant way. Although Putin continues to espouse his belief in nanotechnology's ability to revolutionize life in Russia, recent actions on the part of the government may stymie Russia's growth. In April 2013, the Accounting Chamber—responsible for auditing government programs—accused RusNano of investing approximately $40 million in shell companies and further decried the company's $450 million investment in a silicon factory that was not functioning and declared insolvent.[137] Furthermore, the Accounting Chamber reported that RusNano lost 2.5 billion rubles—approximately $80 million USD—in 2012 and

[135] Carlota Perez, "Technological Revolutions and Techno-Economic Paradigms," The Other Canon Foundation: Norway and Talinn University of Technology, January 2009.

[136] Ibid.

[137] Leonid Bershidsky, "Power Gap Trumps Nanotechnology in Putin's Russia," *Bloomberg World View*, 16 May 2013.

also lost an additional 24.4 billion ruble reserve that the government had formed against potential losses from risky ventures. Rather than support the head of RusNano, Putin appeared on a widely televised call-in program and spoke in a manner that clearly indicated that the program is out of favor with the Kremlin. This is especially problematic for Russia's current economic plan, which had development and eventual privatization of much of the country's nanotechnology research at its center. Given the Russian government's enormous investment in nanotechnology to this point, it is unlikely that this scandal will be problematic for RusNano; however, if the program flounders and remains entirely in state control, Russia's nanotechnology sector runs the risk of falling into the inefficient model of innovation outlined by Evangelista. The Russian military may eventually undergo change on a large scale due to the introduction of nanotechnology into many of its conventional weapons, but the widespread political and societal changes described above may never come to fruition. There is a chance, therefore, that nanotechnology may not prove to be a disruptive technology for Russia.

Continued Research

In-depth study is necessary to identify and measure the extent to which the industry of nanotechnology has demonstrated or is experiencing, what has been defined as an "upheaval of the wealth-creating potential of the economy, opening a vast innovation opportunity space and providing a new set of associated generic technologies, infrastructures and organizational principles that can significantly increase the efficiency and effectiveness of all industries and activities."[138]

3. Maturity of the Nanotech Industry: Institutionalized vs. Transitory Programs

Variable Significance

Investment in nanotechnology generally occurs in two waves. Initially, governments will fund basic research initiatives. They will then require private investment to commercialize such

[138] Carlota Perez, "Technological Revolutions and Techno-Economic Paradigms," The Other Canon Foundation: Norway and Talinn University of Technology, January 2009.

nanotechnological advancements into industry solutions. It is important to differentiate between the two phases of development because in general research programs that are institutionalized have the opportunity to mature in well-funded stable environments, while transitory programs, if not consumed into an existing institutionalized program often fall into the development gap between basic research and commercialization, known as the "valley of death." Therefore, the level the institutionalization of nanotech R&D program serves as a measurement of a program's level of development and maturity.

IR Theoretical Framework

Domestic as well as international organizations and corporations serve as the foundation upon which the research and development of nanotechnology is built. Institutions such as universities drive basic research initiatives and often work in conjunction with other university institutes around the world. Due to the nascent nature of research and development of nanotechnology spanning numerous industries, as well as the cost associated with basic research, international collaborative initiatives have emerged. Such examples of collaboration can be seen in shared research funding between China and the United States.[139]

Participation of national institutes in international co-operative initiatives can be understood as an extension of the participating nations' self-interests. There is widespread anticipation that nanotechnology will be a critical component in addressing global challenges in such areas as energy, environment, health care, security, and sustainability. In order for one nation to effectively respond to the noted emerging global challenges, it is imperative to glean the most from R&D initiatives in the field of nanotechnology. International collaboration is currently the most effective means to further research throughout the field of nanotechnology.

[139] Jon Toon, "International Collaboration Boosts Nanotechnology Research," Research News and Publication Office Georgia Tech, December 2010.

Metrics for Assessment and Proposed Assessment Type

The extent to which nanotechnology has become institutionalized can be measured by the extent to which it is used in the manufacturing or as a component of commercialized products. Using data gathered from the following sources, this section presents a [qualitative and/or quantitative] assessment of the commercial use of nanotechnology:

- Data from 2009 NCMS Study of Nanotechnology in the U.S. Manufacturing Industry
  - Nanotechnology Markets and Commercialization Timelines for 2010–2015
  - Nanotechnology Products Commercialized or In Development (reported in 2009 NCMS study)
  - Distribution of 270 Responses Across Nine Technology Readiness Levels 1–9 (as defined by the NCMS study)
- Data from the Federal State Statistics Service (Rosstat), the Ministry of Education and Science of the Russian Federation, the Federal Service for Intellectual Property, Patents and Trademarks (Rospatent), the Interstate Statistical Committee of the CIS, the OECD, and original methodological techniques of the CSRS
  - Nanotechnology section of the 2011 Russian Science and Technology at a glance report

Preliminary Findings

The National Science Foundation sponsored the National Center for Manufacturing Sciences (NCMS) to conduct a study of commercial approaches to nanotechnology from 2008–2010. A 20-question online survey questionnaire was delivered in mid-2009 to targeted industry executives with strategic and technology oversight, and followed up with selected cross-industry interviews. Datasets from 270 respondents were analyzed for assessing the viability, competitiveness, and sustainability of U.S. nanotechnology organizations. Important results from the study are organized in **Table 2**.[140]

Table 2: Results from the National Center for Manufacturing Sciences (NCMS) 2009 Survey	
Organization Role in Nanomanufacturing	Over two-thirds of the respondents indicated their organizations were directly involved in nanomanufacturing value-chains: product development, raw materials, processes, equipment, and instrumentation.
Profile of Respondents	50% of the respondents hold senior business or technical positions in nanotechnology organizations; a higher number of academic and research organizations are licensing intellectual property (IP) to established corporations.
Collaborative Development of Nanotechnology	The majority (80%) of organizations are involved in collaborations, ranging from single-company partnerships to co-creation in application-focused partnerships. The development of nanotechnology ecosystems is progressing with greater differentiation and product diversity.
Interactions with NNI	Half the respondents (46%) stated their organizations had formal interactions with NNI projects or accessed specialized facilities in the government R&D networks; however, less than 5% indicated licensing IP.

[140] National Center for Manufacturing Sciences, "2009 NCMS Study of Nanotechnology in the U.S. Manufacturing Industry," National Science Foundation, 23 August 2010.

Table 2: Results from the National Center for Manufacturing Sciences (NCMS) 2009 Survey	
Commercialization Timeline	A significant proportion of respondents (25%) indicated their organizations have launched commercial nanotechnology products. By 2013, nearly 80% of respondents' organizations expected market-ready products.
Nanotechnology Products	A broad range of products incorporating nanotechnology are already commercialized or in varying stages of development. Early applications include: nanomaterials for functional coatings, structural reinforcements, energy conversion, displays, drug delivery, diagnostics, and biomarkers.
Nanotechnology Readiness Levels	Readiness Levels 4 (TRLs) 1-3 (38% in conceptual and early stages of applied R&D), and at high TRLs 8-9 (24% nearing implementation-readiness). 30% of the organizations were working at mid-TRLs 4-7, which coincide with the "valley of death" stage in commercialization potential, in which a large amount of resources are required to demonstrate a prototype product application, document performance, and pursue manufacturing pilot and scaling initiatives.
Barriers to Nanomanufacturing	Businesses commercializing nanotechnology face a number of technical, business, safety, and regulatory challenges. The relative ranks

Table 2: Results from the National Center for Manufacturing Sciences (NCMS) 2009 Survey	
	of the top barriers were generally unchanged from the 2005 NCMS Industry Survey, with over 50% indicating the lack of investment capital as a key barrier.
U.S. Competitiveness in Nanotechnology	The U.S. presently leads the world in commercializing nanotechnology, but over two-thirds (70%) of polled executives indicated its leadership is threatened by foreign competition in nearly every application sector.

Russian manufacturing continues to introduce novel nano-enabled products as well as incorporating advancements in nanotechnology into improving existing products. Russia continues to increase the manufacturing of nano-enabled products, resulting in an approximate 90% growth between 2008 and 2010 The significant jump in the value of nanotech-manufactured products in Russia can be contributed to leap in refined petroleum products output. In 2010, Russia introduced $9.9 million USD of novel nano-enabled manufactured products to the world market. See **Table 3**. [141]

[141] Data from the Federal State Statistics Service (Rosstat), the Ministry of Education and Science of the Russian Federation, the Federal Service for Intellectual Property, Patents and Trademarks (Rospatent), the Interstate Statistical Committee of the CIS, the OECD, and original methodological techniques of the CSRS.

Table 3: Russian Nanotechnology-Related Innovation Products of Industry Organizations Implementing Technological Innovation by Economic Activity (millions USD)

	Nanotechnology-related Innovation Products			Including:					
				New for the Sales Market of Organizations			New for the World Market		
	2008	2009	2010	2008	2009	2010	2008	2009	2010
Total Manufacturing:	17.832	32.918	1622	3.7332	5.6519	73.26	0	0.3402	9.964315
Food products including beverages and tobacco	5.5017	-	16.12	-	-	-	-	-	-
Textiles and wearing apparel	-	-	0.009	-	-	-	-	-	-
Refined petroleum products	-	4.3492	1469	-	-	-	-	-	-
Chemicals and chemical products	-	1.3517	4.168	-	-	4.168	-	-	-
Basic metals and fabricated metal products	-	1.177	8.938	-	-	5.587	-	-	-
Machinery and equipment	3.0374	4.2849	41.96	2.7033	0.5578	32.91	-	0.3402	7.972065
Electrical, electronic, and optical equipment	8.2663	13.468	63.86	-	5.0389	30.59	-	-	1.99225
Transport machinery	0.3157	0.0552	-	0.3157	0.0552	-	-	-	-
Materials and substances	0.7111	8.2326	18.18	0.7141	-	0	-	-	-

RUB	**USD**
1	0.03065

By 2015, Russia is expected to have produced $900 billion USD worth of nano-enabled products. In order to meet achieve this level of production, the necessary revenue goals between 2008 and 2015 are outlined in **Table 4**. [142]

Table 4: Russian Nano-enabled Products Projected Revenue Goals between 2008 and 2015 (in billions of USD)

	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Total Investments	0.73	0.86	1.03	1.03	1.05	1.13	1.25	1.48
Sales of Russian Nanoindustry Products	0.71	2.86	5.54	8.57	12.14	16.79	23.3	32.14
Share of World Market of Nanoindustry Products	0.07%	0.25%	0.45%	0.80%	1.25%	1.85%	2.40%	3.00%
Volume of Exports of Nanoindustry Products	0.14	0.93	0.68	1.11	1.86	2.89	4.43	6.43

The difference between technoparks and other forms of innovative organizations is that a technopark's initial infrastructure and all initial investments are subsidized by the government. Technoparks are an innovative aspect of Russia's R& D organizational structure, bridging the development gap between basic research and product commercialization.[143]

- The major corporate objective of a technopark is usually formalized in a statutory document and is worded more or less like this: "The creation of favorable conditions for the development of small and midsize businesses in the sphere of

[142] Julie Bachtold, "Russia Nanotechnology," OSEC Business Network Switzerland, February 2011.

[143] Igor Ustimenko, "Market Insight: Myths and Realities of Technoparks in Russia," *Gartner,* 25 March 2011.

scientific-technical innovations and production by creating material and technical, economic and social resources for the functioning of such enterprises."[144]

- Russia is developing Nano Teknoparks in Tomak and Novosibirsk (West Siberia), Kazan (Tatarstan), Zelenograd (Moscow Region), and Dubna (Moscow Region).[145]
- Russia's government has invested a total of $202.8 million USD in the development of Nano Teknoparks, as shown in **Table 5**.[146]

<table>
<tr><td rowspan="8">Table 5: Committed Government Technopark Development Investment (millions USD, 2011)</td><td>Kaluga</td><td>17.2</td></tr>
<tr><td>St. Petersburg</td><td>17.7</td></tr>
<tr><td>Tatarstan</td><td>7.8</td></tr>
<tr><td>Nizhny Novgorod</td><td>23.5</td></tr>
<tr><td>Novosibirsk</td><td>30.7</td></tr>
<tr><td>Kemerovo</td><td>28.2</td></tr>
<tr><td>Penza</td><td>38.3</td></tr>
<tr><td>Samara</td><td>39.4</td></tr>
</table>

Despite the potential for the Russian nanotechnology sector to fall back to the Soviet model of military innovation, there are positive indicators that the technology is facilitating growth. Russian manufacturing continues to be one of the largest sectors of employment of nanotechnology, with a 90% increase in the manufacturing of nano-enabled products between 2008 and 2010.[147] The products are largely employed by the petroleum industry, which accounts for much of the growth. However, nano-enabled products are also appearing in the production of food and beverages, textiles, chemicals and chemical products, basic and fabricated metal products, machinery and equipment, and much more. By 2015, Russia is expected to have

[144] Ibid.

[145] RusNano: USRBC's 18th Annual Meeting "From Silicon Valley to Skolkovo: Forging Innovation Partnerships," *Fostering Innovations in Russia through Nanotechnology*, October 2010.

[146] Igor Ustimenko, "Market Insight: Myths and Realities of Technoparks in Russia," *Gartner,* 25 March 2011.

[147] A. I. Terekhov, "Evaluating the performance of Russia in the research in nanotechnology," *Journal of Nanoparticle Research*, 2012, 14(11), article: 1250, 3.

produced $900 billion in nano-enabled products, bringing it to a projected 3% of the world market in the nanotechnology industry.[148]

Continued Research

More research needs to be devoted to disaggregating the value added of nanotechnology as it pertains to the overall value of the final product. Additional data also needs to be collected on the revenue projections of the global nanotechnology industry, as well as more specifically revenues of commercialized U.S. nano-enabled products so that a true comparison of the rates of commercialization of nanotech products between the U.S. and Russia can be made.

4. Origin of Technology: Private vs. Public Investment

Variable Significance

Funding for nanotechnology originates from two primary sources, the first being government and the second being private capital either through R&D investment in-house at large corporations or through venture capital (VC) funding. Funding within the nanotechnology industry consists of five primary phases: basic research, applied science, commercialization, market entry, and mature markets.[149] In the United States particularly, government funding primarily supports basic to applied research and heavily relies on industry to oversee the transfer of technology via commercialization. It is argued, however, that even when breakthroughs occur in basic research, due to inadequate funding such advancements are unable to make it to a point of maturity/acceptable risk that a corporation would be willing to invest.[150] Therefore, if a technology is in the downstream phase, receiving a majority of private investment its indicative of the advanced stage in the development and ultimate commercialization of the technology or the industry itself. In addition to indicating the maturity of the technology, the origin of funding

[148] Julie Bachtold, "Russia Nanotechnology," OESC Business Network Switzerland, February 2011.

[149] Tom Crawley, Pekka Koponen, Lauri Tolvas and Terhi Marttila, "Finance and Investors Model in Nanotechnology," *OECD/NNI International Symposium on Assessing the Economic Impact of Nanotechnology* March 2012.

[150] Ibid.

will have implications for the specific areas of development in which it is invested. For example, the United States' National Nanotechnology Initiative released the Supplement to the President's 2013 budget[151] highlighting the following three signature initiatives:

- Sustainable Nanomanufacturing
- Solar Energy Collection and Conversion
- Nanoelectronics for 2020 and Beyond

In total the three signature initiatives were allocated $306 million USD, which was distributed amongst specified government agencies and programs.[152] Unlike private industry in which corporations have the autonomy to innovate freely, programs that originate within government are restricted within an assigned area in which to innovate.

While industry strives to produce advanced nano-enabled commercial off-the-shelf (COTS) systems, defense industries also continue to conduct research and development of nano-enabled military capabilities. However, due to the complex nature of nanotechnology, it is extremely difficult to deduce with certainty the range of potential applications by simply being presented with advancement in particular nanotechnology. The continued commercialization and manufacturing of nano-enabled products/solutions within private industry allow the military to apply COTS solutions to expand upon existing military capabilities. However, the extent to which military will adopt such nano-enabled COTS systems is still purely speculative. Admiral Jeremiah's comments underscore the potential impact of advancements in nanotechnology either pursued independently by military or via the application of a COTS solution.[153] In efforts to prevent a proliferation in highly destructive nanoweapons, analyzing future applications of nanotechnology will direct regulatory initiatives as well as shape the national security landscape moving forward.

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[151] Subcommittee on Nanoscale Science, Engineering, and Technology Committee on Technology National Science and Technology Council, "The National Nanotechnology Initiative: Supplement to the President's 2013 Budget."

[152] Ibid.

[153] David E. Jeremiah, "Nanotechnology and Global Security," *Foresight Conference on Molecular Nanotechnology*, November 1995.

IR Theoretical Framework

The security dilemma provides strong motives for fast innovation because technological superiority is a seen as a decisive factor in armed conflict. A nation armed with advanced nano-enabled capabilities could in theory disarm potential competitors; this would ultimately result in an arms race marked with bursts of innovation and the continued degradation of the security environment. The lack of transparency and the ambiguity associated with identifying nano-weapons as either offensive of defensive systems further exacerbates the imbalance of power and security dilemma, thus contributing to a potential nano-arms race.

Militaries can benefit from technological advances in civilian technology, primarily in the field of information technology, because civilian technology is often more advanced than military technology.[154] At the same time, the civilian sector can benefit from advancements made in the military technology base. As defense budgets shrink, development costs rise, and global competition in civilian markets produce continuous innovation at seemingly exponential rates, the application of the dual-use approach of integrating of military and civilian technologies is increasing.[155] As the integration of both military and civilian technologies increases, this further complicates identifying technologies as having either civilian or military applications.

Metrics for Assessment and Proposed Assessment Type

- Estimated Total International R&D Funding[156]
    - (Public and Private) (2001–2010)
- Total Venture Capital Funding (2001–2010 USD)[157]

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[154] Derek Braddon, "Commercial Applications of Military R&D: U.S. and EU Programs Compared," Conference Proceedings; Pittsburgh, Pennsylvania, 1999.

[155] Subcommittee on Nanoscale Science, Engineering, and Technology Committee on Technology National Science and Technology Council, "The National Nanotechnology Initiative: Supplement to the President's 2013 Budget."

[156] Mihail C. Roco, "The Long View of Nanotechnology Development: The National Nanotechnology Initiative at Ten Years."

[157] Tom Crawley, Pekka Koponen, Lauri Tolvas and Terhi Marttila, "Finance and Investors Model in Nanotechnology," *OECD/NNI International Symposium on Assessing the Economic Impact of Nanotechnology* March 2012.

- Final products market: projection for the worldwide market of finite products that incorporate nanotechnology
    - Interval Variable: Total Market size USD (private investment)
    - Interval Variable: Total Market size USD (public investment)
        - Categorize the field of nanotechnology as in the European Nanotechnology Landscape Report[158] and analyze investment per nanotechnology subfield across both private and public investment

Preliminary Findings

In 2010, Russia's domestic expenditure on R&D of nanotechnology totaled $1.8 billion USD, with expenditure by Russian national corporations such as RusNano totaling over $592 million USD, $565 million USD in public funds (both federal and regional), and $12 million USD (private funding), as shown in **Table 6**.[159] With only 0.7% of Russia's nanotech R&D coming from private investment, Russia's nanotechnology industry currently remains heavily influenced by government policies.

[158] Observatory NANO, "The European Nanotechnology Landscape Report."

[159] Data from the Federal State Statistics Service (Rosstat), the Ministry of Education and Science of the Russian Federation, the Federal Service for Intellectual Property, Patents and Trademarks (Rospatent), the Interstate Statistical Committee of the CIS, the OECD, and original methodological techniques of the CSRS, "Russian Science and Technology at a Glance: 2011."

Table 6: R&D Institutions Engaged in Nanotechnology by Ownership	**Intramural Expenditure on R&D (millions USD)**		
	2008	2009	2010
Total	989.1368	1337.511	1810.146
Russian Ownership	335.9914	445.8104	592.4737
Public	314.9349	428.4809	565.3301
Public (Federal)	314.9349	428.3215	565.1032
Public (Regional)	0.260525	0.15938	0.22681
Private	11.53053	9.63636	12.61554
Joint (w/o foreign)	9.51989	7.696215	14.52504
Joint Ownership with both Russian and foreign participation	1.964665	17.40614	59.87171

Russia is currently in the midst of attempting to spur investment in nanotechnology through a hybrid model of private and public investment. In this way, the Russian government seems to be drawing on the successful creation of nanotechnology in a variety of countries including the United States and China, where the government begins the nanotechnology initiative through the investment of a large sum of money but gradually reduces the amount of public support as private investors begin to invest in various corporations. The Russian government aims to stimulate this investment through RusNano and a number of technoparks around the country. RusNano was specifically designed to complement the projects funded by the Skolkovo Foundation in that RusNano is meant to focus on later-stage projects while Skolkovo is dedicated to fostering those in the early stages.[160]

RusNano sought to attract established nanotechnology corporations to the country by exploiting its relatively late entry into the nanotechnology sphere. Rather than simply invest in existing Russian corporations, RusNano actively purchased large shares of corporations that needed

[160] J.Q. Trelewicz, "An Analysis of Technology Entrepreneurship in the Modern Russian Economy exploring SEZ, Technoparks, and the Skolkovo Program," *IEEE International Technology Management Conference*, 2012, 290.

funding to survive. Such moves served two purposes: removing a stable nanotechnology company from a rival state while also expanding the Russian nanotechnology center into a variety of different industries. For example, in October 2011, RusNano invested a total of $50 million in two American bioscience firms, BIND and Selecta. While the two companies remained based in the United States, both agreed to establish subsidiaries in Russia and to "conduct full-cycle drug development—from R&D through manufacturing and commercialization—and enhance access to high growth pharmaceutical markets."[161] A cursory glance at RusNano's portfolio of companies reveals projects as diverse as Aquantia Corporation, a Silicon Valley-based semiconductor start-up seeking to enhance cloud computing and "development of next-generation Ethernet solutions;" LED Microsensor NT, a company specializing in the "production of semiconductor optical elements for the mid-infrared spectrum;" and TBM, a company that produces "basalt fiber construction materials for Russia's Far East and other regions with permafrost conditions."[162]

Such diversity is imperative for both commercial and military advancements in the future, and each of these companies might play an important role in future military development. Again, the extent to which RusNano funds companies for military R&D is unclear; however, the same scientific breakthroughs needed to produce nanoelectric components that will revolutionize cybersecurity or lightweight, inexpensive UAVs is needed to create and market next-generation Ethernet solutions or basalt fiber construction materials for regions with permafrost conditions. The desired outcome or application may be slightly different, but the requisite knowledge is the same. As such, it is safe to assume that that the origin of Russia's military R&D for nanotechnology is publically funded and that the government may draw on the breakthroughs of scientists working purely in the commercial sector to further its military goals.

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[161] "RusNano Invests in Selecta Biosciences and BIND Biosciences. To Develop and Commercialize Cancer Drugs in Russia," *nanowerk*, 27 October 2011, par. 3.

[162] "RusNano Portfolio Companies," RusNano, http://en.rusnano.com/portfolio/companies.

By comparison, in 2013, the United States across fifteen federal agencies has a proposed nanotech budget of $1.765 billion USD, as shown in **Table 7**.[163]

Table 7: Investments by U.S. Agencies

FY 2009-2013 (millions USD)

FY	2009	2010	2011	2012 (estimated)	2013 (proposed)
DOE	625.8	373.8	346.2	315.4	442.5
DHHS / NIH	416.2	456.8	408.6	409.6	408.7
NSF	509.8	428.7	485.1	426.0	434.9
DOD	459.0	439.6	425.3	361.2	289.4
DOC / NIST	136.8	114.7	95.9	95.4	102.1
NASA	13.7	19.7	17.0	23.0	22.0
EPA	11.6	17.7	17.4	17.5	19.3
DHHS / NIOSH	6.7	8.5	10.0	10.0	10.0
DHHS / FDA	6.5	7.3	9.9	11.8	11.1
USDA / NIFA	9.9	13.2	10.0	10.0	10.0
DHS	9.1	21.9	9.0	7.0	6.0
USDA / FS	5.4	7.1	10.0	2.0	5.0
CPSC	0.2	0.5	1.8	2.0	2.0
DOT	0.9	3.2	1.0	1.0	2.0
DOJ	1.2	0.2	0.0	0.0	0.0
Total[†]	**2212.8**	**1912.8**	**1847.2**	**1691.9**	**1765.0**

Continued Research

Data was not readily available for U.S. private nanotech investment; further research is required.

[163] "NNI Supplement to the President's FY 2011 and 2013 Budget," http://nano.gov/sites/default/files/pub_resource/nni_2013_budget_supplement.pdf and http://www.nano.gov/NNI_2011_budget_supplement.pdf

5. Higher Education and Research Institutes: Indicator of Capacity and Collaboration

Variable Significance

Higher education university and research institutes serve as ground zero for technological innovation and collaboration. There is a growing need for engineers who can fill several roles required to transform nanotechnology from basic science to commercialized industry solutions. In effort to meet that need, programs such as the Nanotechnology Undergraduate Education (NUE) Program initiated in 2003 offer support to undergraduate institutions in the following areas: curriculum/course development; laboratories and/or modules development; and ethical, societal, economic, and environmental implications of nanotechnology.[164] Universities and research institutes are also recipients of federal grants that fund study in specific areas of basic and advanced science. Universities are also often equipped with laboratories stocked with advanced technology that are readily available to both staff and students. In addition to the collaboration between researchers, professors, and students, the university setting also fosters collaboration between universities across fields. Because the need for skilled engineers is so high, developed nations are able to reap the benefits of the brain drain from developing countries by encouraging foreigners who earn an advanced technical degree not to return home and instead to join the pool of domestic scientists.

Metrics for Assessment and Proposed Assessment Type

- Brain Gain
  - Interval variable measuring the percentage of foreigners educated in the United States who stay in the United States (undergraduate, graduate, and post-doctoral)
  - Interval variable measuring the percentage of all foreign educated citizens who stay in the country in which they received their education (undergraduate, graduate, and post-doctoral)

[164] Subcommittee on Nanoscale Science, Engineering, and Technology Committee on Technology National Science and Technology Council, "The National Nanotechnology Initiative: Supplement to the President's 2013 Budget."

- Brain Drain
  - Interval variable measuring the percentage of foreigners educated in the United States who leave the United States
  - Interval variable measuring the percentage of all foreign educated citizens who leave the country from which they received their education (undergraduate, graduate, and post-doctoral)
- University and higher institutions
  - Number of undergraduate universities that have nanotechnology programs
    - United States
    - International
    - Number of professors and students in the program
  - Number of graduate universities that have nanotechnology programs
    - United States
    - International
    - Number of professors, graduate, and PhD students in the program
- Published ISI articles

Preliminary Findings

In 2012, 19% of Russia's total published ISI articles were nano-related while only 10% of the United States' total published ISI articles were nano-related. In 2012, however, the United States published 15,154 ISI articles while Russia only published 2,044. The difference in absolute numbers is substantial without even addressing quality. See **Table 8**.[165]

165 Nano Statistics, "Science, Technology, and Industry Scoreboard."

Table 8: U.S. and Russian ISI Nano-Articles						
Total Number of Citations of all Nano-Articles						
	2007	**2008**	**2009**	**2010**	**2011**	
United States	236,064	204,782	158,483	103,837	45,179	
Russia	14,383	11,164	9,143	5,421	2,152	
Share of Joint Nano-articles Between Countries						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
United States	25.1	32.1	34.9	36.8	38.8	40.5
Russia	39.9	38.7	37.8	39	36	38.2
Number of ISI Nano-Articles						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
United States	13,542	14,785	15,587	17,409	18,747	15,154
Russia	2,136	2,342	2,521	2,713	2,845	2,044
Nano ISI Articles as a Percentage of Total ISI Articles						
	2007	**2008**	**2009**	**2010**	**2011**	**2012**
United States	4.65%	14.79%	15.59%	5.39%	5.75%	10.10%
Russia	8.58%	9.55%	10.02%	10.16%	10.35%	18.85%

In 2010, Russia reported 480 nanotech institutions, employing 17,928 researchers. See **Table 9**.[166]

Table 9: Russian R&D Institutions Engaged in Nanotechnology by Sector of Performance

	Institutions			**Researchers**		
	2008	2009	2010	2008	2009	2010
Total	463	465	480	14873	14500	17928
Government Sector	165	171	178	6537	6554	7267
Business Enterprise Sector	128	128	134	5654	4330	5608
Higher Education Sector	**168**	**164**	**167**	2652	3581	5022
Private Non-Profit Sector	2	2	1	30	35	31

The Russian institution that has produced the most nanotech related publications between 1976 and 2007 is the Russian Academy of Science with a total of 6,773 publications; Moscow Mv Lomonosov State University produced the second highest number of publications totaling 1,421. See **Table 10** for the comprehensive listing of the top ten institutions in nanotechnology paper publication in Russia between 1976 and 2007.[167]

166 Data from the Federal State Statistics Service (Rosstat), the Ministry of Education and Science of the Russian Federation, the Federal Service for Intellectual Property, Patents and Trademarks (Rospatent), the Interstate Statistical Committee of the CIS, the OECD, and original methodological techniques of the CSRS, "Russian Science and Technology at a Glance: 2011."

167 Xuan Liu, Pengzhu Zhang, Xin Li, Hsinchun Chen, Yan Dang, Catherine Larson, Mihail C. Roco, and Xianwen Wang, "Trends for nanotechnology development in China, Russia, and India," *Journal of Nanoparticle Research*, November 2009, 11(8).

Table 10: Top 10 institutions in nanotechnology paper publication in Russia (1976–2007)				
Rank	**Institutions in Russia**	**# in 2000**	**# in 2007**	**# in 1976–2007**
1	Russian Academy of Sciences	443	989	6,773
2	Moscow Mv Lomonosov State Univ	78	225	1,421
3	AF Ioffe Phys Tech Institute	67	53	649
4	St Petersburg State University	23	73	397
5	Ufa State Aviat Tech University	10	18	194
6	Joint Institute of Nuclear Research	5	30	140
7	Boreskov Inst Catalysis	10	19	137
8	Si Vavilov State Opt Inst	6	11	135
9	Novosibirsk State University	9	0	110
10	Technical University	5	27	106

As discussed above, the Russian government has made a concerted effort in recent years to improve the collaboration between universities and research institutes. The fruits of these efforts are beginning to emerge in the country's nanotechnology industry, where universities now employ a number of researchers comparable to the research institutes. Despite a loosening of the restrictions on universities' ability to collaborate with research institutes, deep similarities in the structure of Russian scientific research remain. The RAS continues to dominate other research institutes in the country in almost every measure of research about nanotechnology. Seven RAS institutes are among the most prolific publishers in the field of nanotechnology in the country, mirroring the state of the research sector under the Soviet Union.[168] While Moscow State University (MSU) boasts a larger number of publications since laws allowing collaboration between universities and research institutes were passed in 2006, it is increasingly difficult to disaggregate which papers are truly written and published by members of the university

[168] A. I. Terekhov, "Evaluating the performance of Russia in the research in nanotechnology," *Journal of Nanoparticle Research*, 2012, 14 (11), 1250, 11.

community and which were authored primarily by researchers for the RAS who split their time between a research institute and a university. As such, while the universities seem to be gaining legitimacy and recognition within the Russian R&D community, it is entirely possible that the new laws simply created a scenario where universities and research institutes operate in much the same way but manipulate the data to their advantage.

If this is the case, it once again underscores the similarities between the contemporary Russian Federation and the Soviet Union. Not only do universities in many countries serve as an important incubator for technological advancement and innovation by allowing researchers in university laboratories to experiment freely, but, as discussed above, incorporating universities into RAS research institutes could help eliminate the "brain drain" that plagues scientific research in the country currently. If cooperative agreements are made between research institutes and universities purely for show rather than to enhance the flow of information between the two, many of the benefits ascribed to this relationship will fail to appear in Russia.

Despite the uncertainty about where well-respected nanotechnology research is originating in the R&D apparatus, however, authors and individual research institutions are beginning to make their mark in particular areas of nanotechnology research. Terekhov was able to isolate both the most prolific individual authors and the most prolific institutions in the field. Searching the Science Citation Index Expanded (SCIE) for a variety of terms related to nanotechnology indicated that nearly 12.1% of the publications with more than 100 citations were focused on nanophotonics. The three most-cited articles in this subset came from scientists at the Institute for Physics of Microstructure, the Institute for Spectroscopy (IS) and the Shubinikov Institute of Crystallography (IC), all of which are part of the RAS.[169] Nine publications focusing on "nano-bio-med" also were cited more than 100 times each, indicating that the papers are gaining some recognition worldwide. These publications are far more widespread in the RAS and university systems, however. Authors of these articles hail from the Blokhin Russian Cancer Research Center of the Russian Academy of Medical Sciences (RAMS), the Schenov Moscow Medical Academy, the Moscow Research Institute of Medical Ecology, the Research Institute of Human Morphology RAMS, the MSU, and the Shemyakin-Ovchimnikov Institute of Bioorganic

[169] Ibid., 10.

Chemistry (IBC) RAS. This is perhaps indicative of a greater amount of collaboration between universities and research institutes in this area than in other fields of nanotechnology research.

While the number of times an article is cited provides a measure of the quality of the work produced from a given university or research institute, isolating the most prolific authors and determining where they work also helps determine the nature of the research being pursued in a given institution. **Table 11** summarizes these findings.[170]

Table 11: Research Direction and Institution of Most Prolific Russian Authors, 1990–2010

Name of Scientist	Institution	Research Direction
Y.E. Lozovik	IS RAS	Physics of nanostrucutres; nanooptics
I.A. Ovid'ko	IPME RAS	Mechanics of nanomaterials
Y.D. Tretyakov	DMS MSU	Functional nanomaterials
E.D. Obraztsova	GPI RAS	Carbon nanostructures
A.M. Zheltikov	DP MSU	Nanophotonics
S.V. Ivanov	PTI RAS	Semiconductor nanostructures
V.K. Ivanov	IGIC RAS	Functional nanomaterials
A.V. Okotrub	NIIC SB RAS	Carbon nanostrucutres
V.G. Dubrowskii	PTI RAS	Semiconductor nanostructures
G.E. Cirlin	PTI RAS	Semiconductor nanostructures

170 Ibid., 12.

This combination of lenses gives some idea of the research going on in the Russian research institutes and universities: PTI RAS has some focus on semiconductor nanostructures, IS RAS some focus on the physics of nanostructures, IPME RAS on the mechanics of nanomaterials, IGRIC RAS on functional nanomaterials, and NIIC SB RAS on carbon nanostructures. Perhaps more interesting is the fact that, while the work on nanophotonics produced by Russian authors caught the attention of the international community during this time, only one of the country's most prolific authors researches in that field. This might indicate that work on nanophotonics is more widespread throughout the R&D apparatus than research on semiconductor nanostructures appears to be.

Reviewing the RusNano portfolio on its website indicates a somewhat similar breakdown of research priorities. RusNano divides its portfolio into six technological fields: nanomaterials, optics and electronics, medicine and pharmacology, energy efficiency, coating and surface modification, and other. These technological fields comprise 44%, 10%, 17%, 15%, 10%, and 4% of the portfolio respectively.[171] Such a breakdown seems to align roughly with the specifics that Terekov's study unveiled. Nanomaterials seem to comprise the largest portion of research into nanotechnology, pharmaceuticals the second largest, and so on.

Also of interest is that Russian collaboration with international scientists appears especially strong in nanotechnology research. Although nanotechnology articles by Russian scientists were not frequently cited in an examination of articles included on the Science Citation Index Expanded database—articles authored solely by Russian scientists averaged only 5.1 citations—articles that Russian scientists collaborated on with foreign scientists received an average of 42.3 citations.[172] While not a scientific measure, this could be indicative of Russian nanotechnology researchers receiving the support Russia seeks to foster between its universities and research institutes from foreign researchers and universities. This is not an ideal solution to the problem at hand, but it may indicate that Russian researchers are exposed to more liberal thinking and

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[171] Nikita Dulnev, "Rusnano's Big Nanotechnology Secrets Revealed," *Russia Beyond the Headlines*, 3 August 2011, par. 2.

[172] A. I. Terekhov, "Evaluating the performance of Russia in the Research in Nanotechnology," *Journal of Nanoparticle Research*, 2012, 14 (11), 1250, 11.

innovation than solely studying the domestic relationship between Russian research institutes and universities seems to support.

Continued Research

More research is needed in order to measure reverse brain drain. Further data needs to be collected to calculate the percentage of foreigners educated in the United States who stay in the United States (undergraduate, graduate, and post-doctoral) and the percentage of all foreign educated citizens who stay in the country in which they received their education (undergraduate, graduate, and post-doctoral). Data also needs to be collected to effectively measure for brain drain: the percentage of foreigners educated in the United States who leave the United States as well as the percentage of all foreign educated citizens who leave the country from which they received their education (undergraduate, graduate, and post-doctoral).

6. Research and Development of Nanotechnology: Overt vs. Covert

Variable Significance

As the nanotechnology industry continues to advance, voluntary transparency in both private industry as well as defense industries will prove to be a critical component in confidence building between nations. Transparency is integral in private industry to mitigate the fears and public distrust of nano-enabled products as well as nano-manufacturing. Transparency will serve to separate facts from fiction that surrounds societal implications of nanotechnology. One such science fiction scenario famously introduced by the "father of nanotechnology," Eric Drexler, is that of "grey goo." In this scenario, self-replicating nano-machines or nano-bots run amok and take over the world.[173] The spread of this wildly speculative doomsday scenario was pervasive enough that, after reading a report issued by the ETC Group, a Canadian watchdog organization on nanotechnology,[174] Prince Charles publically proclaimed his distress.[175] This notional

[173] Lawrence Osborne, "The Gray-Goo Problem," *The New York Times Magazine* (book summary), December 2003.

[174] "The Big Down," *The ETC Group*, January 2003.

scenario is an example of how a lack of transparency associated with the research, development, and manufacturing of an emerging technology leads to an unfounded societal paranoia and fear of the emerging technology.

A lack of transparency about an emerging technology not only negatively effects public perception but also negatively impacts the perceived balance of powers in the existing security environment. Due to the ambiguity associated with categorizing military applications of nanotechnology as either offensive or defensive in nature, the stability of the security environment will inevitably be compromised. Lack of transparency in the research, development, and manufacturing of emerging technologies also makes it extremely difficult to regulate. Even if a transnational regulatory framework is established, it is impossible to determine if a nation is non-compliant if one is unable to determine the entire scope of research, development, or manufacturing.

Like so much else in Russia's development of nanotechnology, the amount of transparency offered by the government is somewhat of a hybrid. President Putin and other high-ranking members of the government have made no secret of their desire to transform Russia into a great power by stimulating the economy through investment in scientific research and development. The focal point of this investment is the government's $7 billion investment in nanotechnology. RusNano, the government's nanotechnology investment arm, has a very detailed website that includes links to a variety of information about the projects and companies in its portfolio, which seems to suggest Russia's development of nanotechnology is overt. RusNano's willingness to partner with foreign firms including MIT also indicates a willingness to share information with other states that is uncharacteristic of the Soviet government during the Cold War.

Finding information about the specific research that the Russian military is conducting on nanotechnology is extremely difficult, however, which prevents Russia's development of nanotechnology from being classified as overt. It is possible to piece together some educated guesses about the sectors of nanotechnology that are most attractive to the Russian government

[175] Lawrence Osborne, "The Gray-Goo Problem," *The New York Times Magazine* (book summary), December 2003.

from records of government hearings and from those areas of defense where Russia has historically dominated. One of these is the aeronautics and space programs, which some military analysts predict will serve as the basis for Russia's attempts to navigate around improved sensors and radar. Specifically, analysts assert that nanobots and nanomachines will become central in this effort due to their inherent stealth properties.[176] Such innovations are hypothesized as critical for Russia's military. Due to demographic shifts, the Russian population is aging rapidly without the possibility of replacement.[177] Therefore, it is speculated that the Russian army will lose the mass that formed the basis of its military capacity for centuries, which will force the leadership to find practical, relatively inexpensive ways to overcome the lack of manpower. Nanotechnology, if embraced and developed, is put forward as having the potential to help Russia overcome this problem.

Continued Research

Although it will be impossible to research the covert nanotechnology research and development programs currently being conducted throughout the world, it is possible to record information on all publically released military nanotechnology research and development.

7. Technological Imperative: Tech Driven vs. Requirements Pulled

Variable Significance

Those who subscribe to the ideology of the "technological imperative" believe that if something is technically possible then action ought to, must, or inevitably will be taken; as Daniel Chandler explains, "the information technology revolution is inevitably on its way and our task as users is to learn to cope with it."[178] If one were to apply the ideology of the technological imperative to understanding potential future implications of advancements of nanotechnology on society, it

[176] Theodore C. Hailes et. al. "Resurgent Russia in 2030: Challenges for the USAF," Center for Strategy and Technology, Air War College, September 2009, 73.

[177] Ibid.

[178] Daniel Chandler, "The Technological Imperative," *Technological or Media Determinism*, 2000.

would suggest that a revolution in nanotechnology will drive changes to policy and ultimately society. As public opinion of advancements in nanotechnology wavers amid rumored consequences that mirror something out of a science fiction movie, the public continues to call for government interference and regulation to ensure the safety and health of the general population.

While Putin and other government leaders continue to place a great deal of emphasis on nanotechnology's potential to pull Russia back into the position of a great power, it would seem that the implementation of the technological imperative is incomplete at best. Soviet military innovation was very slow to embrace new technologies, even if scientists had the ability to develop the technology. This pattern of slow or incomplete innovation serves as the foundation of Adamsky, Evanaglista, and Radosevic's critiques of the government. Such systemic resistance to innovation seems to indicate that the technological imperative did not drive Soviet adoption of military technology.

Contemporary Russia is more difficult to classify given the government's heavy investment in nanotechnology in recent years. Although the government's reliance on nanotechnology indicates a desire to invent anything and everything that might aid the growth of the Russian economy, the development of nanotechnology in the country is so recent that only small changes are evident. If a technological imperative is driving innovation in the country, signs of social and political change would likely be more evident. Perhaps an argument could be made that the government's desire to spur private investment in RusNano and Skolkovo is indicative of a fundamental shift in the manner in which the government approaches innovation, but such an argument is weak. RusNano and Skolkovo are first and foremost government entities and will remain so for the foreseeable future, particularly if RusNano is truly out of favor with the government and therefore unable to engage in the first sell off of the corporation next year.[179] As such, it is difficult to determine how much the government understands of the process of successful innovation is predicated on a top-down model of government involvement and how much relies on foreign investment. Understanding this frame of reference is important because it allows for a clearer picture of the amount of societal and political change that nanotechnology is

[179] Leonid Bershidsky, "Power Grab Trumps Nanotechnology in Putin's Russia," *Bloomberg*, 16 May 2013, par. 7.

creating in the country. If the government truly desires a more open, liberal approach to nanotechnology innovation, it might be indicative of the political and societal changes that a technology driven revolution causes. If, however, RusNano and the more liberal policies are simply included in the laws governing innovation to give the appearance of change, the technological imperative would seem inapplicable.

Continued Research

Categorizing or measuring whether a technological innovation can be considered tech driven or requirements pulled is difficult. However, there are indicators of whether or not a technology can be considered tech driven; for example, a tech-driven technology results in documentable societal changes, such as regulation. Qualitatively, a case can be made for nanotechnology as a tech-driven innovation revolution by applying a similar framework as was proposed in the discussion of the second variable in which innovation was measured through Carlota Perez's techno-economic paradigm.

This work will also be expanded to address DOD's uses of tech driven versus requirements pulled in acquisitions.

8. Regulation of Nanotechnology: National vs. International Regulatory Framework

Variable Significance

Many take the view that "[n]anotechnology is so new and so untested for potential effects on human health that we do not even know what we don't know."[180] Advancements in the field of nanotechnology have already made it into common consumer products including household appliances, automobiles, electronics and computers, food and beverages, children's toys, textiles, paints, cleaning materials, and even sunscreen.[181] Although many of the risks associated with

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[180] Steven Higgs, "Mama, Dada, and Nano?" *The Progressive*, October 2009, 20.

[181] "Products," The Project on Emerging Nanotechnologies. http://www.nanotechproject.org/inventories/consumer/browse/categories/

nano-enabled products are remote and hypothetical, concerns about the potential consequences of nanotechnology and its applications have been voiced. Such concerns include worker safety in the manufacture or use of nanotechnology-based goods; consumer safety; environmental damage caused by manufacturing waste and finished goods that may contaminate air, water or soil; unforeseen consequences of uncontrolled nanotechnology; and potential military applications.[182] Due to these concerns, calls for increasing regulation are not uncommon; however, overregulating an industry in its nascent stage may be counter-productive and hinder potential innovation with deleterious impact on our national security.

Aside from regulation due to environment, health, and public safety concerns, standardization initiatives within the field of nanotechnology are very important to streamline research and to encourage collaboration across borders, fields of study, and industry. Joint standardization efforts will be an important contributor to continued growth and research and development of nanotechnology.

IR Theoretical Framework

Implementing a national regulatory framework will not be sufficient to regulate nanotechnology. Although national regulatory frameworks are best able to promote international competition and diversity in research and development, national approaches may also result in a "race-to-the-bottom in environmental and labor standards," and may be unable to control potential security risks.[183] The speculative risks associated with nanotechnology are in fact cross-boundary issues such as potential environmental dangers. Separating hype from technical reality are crucial factors that are frequently not adequately addressed, e.g., grey goo. Any transnational regulatory framework will have to weigh factors across sectorial boundaries, as well as to speed research and development through sharing expertise and resources and confidence-building measures.

Metrics for Assessment and Proposed Assessment Type

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[182] Gary E Marchant and Douglas Sylvester, "Transnational Models for Regulation of Nanotechnology," *Journal of Law, Medicine & Ethics*, Winter 2006, 716.

[183] Ibid., 717.

- Existing nanotech regulatory bodies
  - Number of regulatory agencies in each country
  - Number of agencies that oversee the regulation of nanotechnology
- Number of international organizations that focus on the regulation of nanotechnology
- Permissive regulation
  - Categories of research and the total corresponding government grants (USD)

Preliminary Findings

The National Economic Council (NEC), the Office of Management and Budget (OMB), the Office of Science and Technology Policy (OSTP), and the Office of the U.S. Trade Representative (USTR) led a multi-agency consensus-based process to develop a set of principles to guide development and implementation of policies for the oversight of nanotechnology applications and nanomaterials. The U.S. federal government has significantly increased funding on the environmental, health, and safety dimensions of nanotechnology, from $37.7 million in fiscal year (FY) 2006 to $123.5 million in FY 2012.[184]

In addressing issues raised by nanomaterials, agencies will adhere to the Principles for Regulation and Oversight of Emerging Technologies. Specifically, to the extent permitted by law, federal agencies will:	
1	To ensure scientific integrity, base their decisions on the best available scientific evidence, separating purely scientific judgments from judgments of policy to the extent feasible
2	Seek and develop adequate information with respect to the potential effects of nanomaterials on human health and the environment and take into account new knowledge when it becomes available
3	To the extent feasible and subject to valid constraints (involving, for example, national security and confidential business information), develop relevant information in an open and transparent manner, with ample opportunities for

[184] OSTP memorandum, "Policy Principles for the U.S. Decision-Making Concerning Regulation and Oversight of Applications of Nanotechnology and Nanomaterials," 9 June 2011.

In addressing issues raised by nanomaterials, agencies will adhere to the Principles for Regulation and Oversight of Emerging Technologies. Specifically, to the extent permitted by law, federal agencies will:	
	stakeholder involvement and public participation
4	Actively communicate information to the public regarding the potential benefits and risks associated with specific uses of nanomaterials
5	Base their decisions on an awareness of the potential benefits and the potential costs of such regulation and oversight, including recognition of the role of limited information and risk in decision making
6	To the extent practicable, provide sufficient flexibility in their oversight and regulation to accommodate new evidence and learning on nanomaterials
7	Consistent with current statutes and regulations, strive to reach an appropriate level of consistency in risk assessment and risk management across the Federal Government, using standard oversight approaches to assess risks and benefits and manage risks, considering safety, health and environmental impacts, and exposure mitigation
8	Mandate risk management actions appropriate to, and commensurate with, the degree of risk identified in an assessment.
9	Seek to coordinate with one another, with state authorities, and with stakeholders to address the breadth of issues, including health and safety, economic, environmental, and ethical issues (where applicable) associated with nanomaterials
10	Encourage coordinated and collaborative research across the international community and clearly communicate the regulatory approaches and understanding of the United States to other nations.

Adapted from OSTP Memorandum: *Policy Principles for the U.S. Decision-Making Concerning Regulation and Oversight of Applications of Nanotechnology and Nanomaterials*, 9 June 2011.[185]

[185] "Memorandum for the Heads of Executive Departments and Agencies," June 9, 2011, http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/nanotechnology-regulation-and-oversight-principles.pdf, 4.

The proposed regulatory framework does not identify a singular definition of what is classified as "nanotechnology." This report argues that for the purposes of oversight and regulation, the critical issue is whether and how such new or altered properties and phenomena emerging at the nano-scale create or alter the risks and benefits of a specific application. A focus on novel properties and phenomena observed in nano-materials may ultimately be more useful than a categorical definition based on size alone.

Despite nanotechnology's growing use in everyday items such as household appliances, automobiles, and sunscreen, national and international regulatory frameworks have yet to be established. Currently, there is very little federal legislation regulating the development and application of nanotechnology in Russia. Additionally, there are no laws containing technical regulations for ongoing projects.[186] Perhaps the closest that Russia comes to a framework of regulation is the *Concept of Toxicological Research*, which provides a methodology of risk assessment and methods for an identification of quantitative detection of nanomaterials. Issued in 2007, this concept includes descriptions and characteristics of new properties and behavior of nanomaterials in environmental and biological objects, the necessity of studying the effects of ingesting each nanomaterial, an analysis of data about the safety of the manufacturing and use of nanomaterials, and the procedure for the oversight of nanotechnology research.[187] Other important regulations issued by the government include the "Assessment on Nanomaterials' Safety," and the "Policy of Nanotechnologies Classification."[188] Some departments within the federal government have also attempted to fill gap by issuing regulation of their own. The Public Health Ministry of the Russian government issued an order on August 5, 2009, which authorized a working group to "organize a development of subordinate and methodical documents covering questions of nanomaterials' and nanotechnologies' safety and methods of Nanosafety Risk Assessment."[189]

[186] Ekaterina A. Belokrylova, "Legal issues of the environmental safety regulation in the sphere of nanotechnology in Russian Federation," *Journal of Physics: Conference Series*: 429, 2013.

[187] Ibid.

[188] Ibid.

[189] Ibid.

Continued Research

Further research is needed in order to capture the ongoing international dialogue surrounding the creation of a global nanotech regulatory framework as well as any emerging regional regulatory nanotech frameworks.

Part IV. Conclusions and Future Directions

The ultimate goal, which is beyond the scope of an initial one-year project, is to develop new theoretical frameworks to explain variable approaches to the development of strategically significant nanotechnology and emerging science programs; to understand their impact on security; to enable mechanisms for the world to govern the implications of its own ingenuity; and to inform security, defense, and foreign policies.

The development of military applications for nanotechnology in the Russian Federation could be perceived as a threat to international security and could spark counter-militarization by states such as the United States, Western Europe, Poland, Ukraine, and Georgia due to the security dilemma. Some Russian elites claim to be militarizing nanotechnology in response to the alleged military advances of the United States. However, the Russian Federation does not currently pose a threat to the international community due to its inability to convert nanotechnology research into development as a result of financial mismanagement and changing views on the infrastructure. The international community recognizes this lack of a threat and therefore the security dilemma is less likely to cause mass militarization and mobilization by states feeling threatened.

This work establishes a codified variable approach to the development of strategically significant nanotechnology and emerging science programs, with the eventual goal of enabling cross-national comparisons. Critical factors in the role and significance of emerging technologies, e.g., institutional, ideational, or technical, have been identified. The application of these variables and their assessment against new data, interviews, and field work done by the author will be explored in future work.