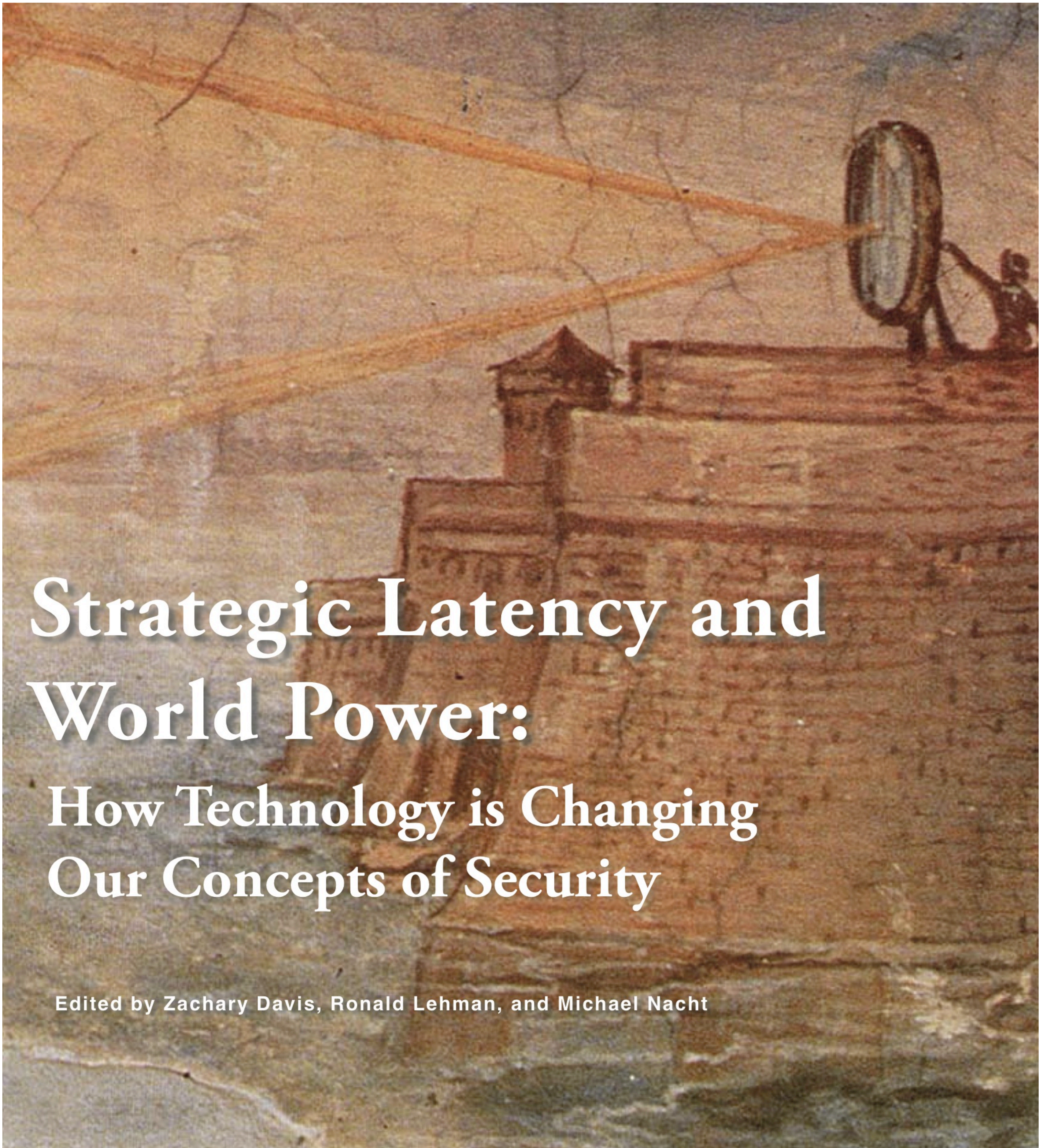

Strategic Latency and World Power:

How Technology is Changing Our Concepts of Security

Edited by Zachary Davis, Ronald Lehman, and Michael Nacht

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About the cover: The cover is a frieze painted by Giulio Parigi around 1600, from the Galleria degli Uffizi in Florence, Italy, depicting the legendary use of a system of mirrors designed by Archimedes to focus sunlight intended to burn up Roman ships invading the Greek city-state of Syracuse in 213 B.C. While the military history of Archimedes' directed energy weapon remains in question, the painting illustrates how technological innovation translates into strategic latency.

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Acknowledgements

The idea for this book came from a meeting of the minds between Ron Lehman and Larry Gershwin, who are the godfathers of strategic latency. They had been thinking on parallel tracks about the accelerating pace of technological progress and its implications for national security. Separately, they had probed government, industry, and academia to assess the technologies with the highest potential to bring revolutionary change. Both had assembled a cadre of experts to track and analyze strategic latency. I attended that initial meeting as one of Ron's acolytes and was introduced to Larry's deputy Frank Gac, who became my partner in developing the concepts and applications behind strategic latency. We found our third collaborator in Michael Nacht, who had recently returned to the University of California, Berkeley, after leading the government's reviews of nuclear and cyber policies in his capacity as assistant secretary of defense. Michael, a highly respected scholar, took our ideas to a whole new level.

Although researchers have different names for what we call strategic latency, such as technological surprise, emerging and disruptive technologies, a community of like-minded experts scattered throughout government agencies, think tanks, academia, national laboratories, and the private sector share a belief in the transformative power of emerging technologies—for better and for worse. This group of technical and policy analysts provided the intellectual fuel for the series of workshops that culminated in this book. The members of this diverse group are united in their belief in the need for a concerted national effort to meet the challenges of strategic latency. We hope this book amplifies their message about the need for the U.S. to sustain its global competitiveness in science and technology.

Managers at Lawrence Livermore and Los Alamos national laboratories and the National Intelligence Council gave us enough rope to either hang ourselves or successfully lash together a coherent story from a disparate collection of people and ideas. We hope we have achieved the latter. Z program director Nils Carlson at Lawrence Livermore, himself a former Gershwin deputy, consistently encouraged our efforts. Deputy national intelligence officer Rhonda Anderson provided many examples of latent technologies, Brian Shaw from National Intelligence University was ahead of us at every turn, and Tom Tierney at Los Alamos worked hard to keep government agencies up to speed. Steve Black and his deputies at the Department of Energy's Office of Intelligence do their utmost to support research into latency issues.

Center for Global Security Research (CGSR) Director Bruce Goodwin and his deputy Mona Dreicer made it possible to bring the manuscript to completion. Sandra Maldonado kept the trains and planes running on time, Paris Althouse added firepower in the late innings, and CGSR fellows Jonathan Pearl, Bob Smolen, Eileen Vergino, Bob Schock, and Don Prosnitz aided and abetted the latency project, while Bob Joseph and Neil Joeck kept us (more or less) tethered to reality. The journal *Orbis* took a leap of faith by publishing my initial article on strategic latency in its winter 2012 issue. My students at the Naval Postgraduate School in Monterey brought their military experience to bear on the prospects for technological change in the ways of modern warfare.

Fate smiled on us when Lawrence Livermore science writer Katie Walter agreed to edit the volume. Her discerning eye for language, expansive technical knowledge, patience, and enthusiasm provided the glue that turned a bunch of interesting papers into a coherent book.

The central place of uncertainty in this endeavor increases the likelihood that errors and misunderstandings will emerge at some point. Since I am the one who coaxed the authors out on this limb, it is I who must take responsibility for any and all mistakes.

— Zachary Davis

Foreword

Strategic latency: What does this mean? That was the question we asked ourselves when Ron Lehman and Zachary Davis requested a meeting with us in November 2009. They promptly explained, "Strategic latency refers to the inherent capacity of science and technology to produce game-changing threats to our national security. . . .The potential for a technology to cause harm is often 'latent' until an adversary uses it for military purposes." Thus began a multiyear journey working together to further define, explore, and explain what strategic latency means to an intelligence officer, a warfighter, an entrepreneur, a scientist, an economist, and others. This book is a grand endeavor that represents an important milestone along that journey, a journey which is ongoing. Nonetheless, we use this foreword to provide a snapshot.

We start by asking the question again: What is strategic latency? By choice, our answer is framed by science and technology because history shows us the combination brings change. With that in mind, our response is: Strategic latency refers to the inherent potential for technologies to bring about significant shifts in the military or economic balance of power. Such potential may remain unexploited or even unrecognized, and thus latent, until a combination of factors coalesce to produce a powerful capability. This list of contributing factors can be extensive but generally three rise to the top: national security, economics, and human welfare.

Note that the ultimate result is a shift in power. Thus, one must understand the many manifestations of power to have a thorough appreciation for the role of strategic latency. It is for this reason the book begins with an introduction entitled, "What Is Power?" The authors then embark on an elaboration of strategic latency, including drawing lessons from the history of nuclear proliferation. This introduction is followed by an insightful investigation of current-day technology case studies, with a focus on lasers, cyber, and additive manufacturing. The final chapter of the book is devoted to case studies of various countries, in which the authors engaged experts to provide a thought-provoking sampling across the innovation spectrum, in the form of Turkey, Brazil, Republic of Korea, Russia, Japan, and China.

Why is the concept of strategic latency important? Many of us would like to predict the future. Knowledge of the future would enable us to prepare or even avoid some problems. At a national level, such problems might consist of military conflict, a pandemic, or economic disruption. Strategic latency, framed in science and technology, can give us insights and thus options for the future. Those insights can foster innovation, help mitigate vulnerabilities, or catalyze a new application of existing technology.

Strategic latency is not the end-all as one attempts to predict disruptive technology and emerging threats. However, it is a valuable tool, and perhaps an overarching philosophy for attacking the problem. The authors are to be commended in taking this first step at capturing this philosophy in book form.

—Lawrence K. Gershwin and Frank D. Gac[1]

[1] Lawrence Gershwin is with the Office of the Director of National Intelligence and Frank Gac is with Los Alamos National Laboratory.

Table of Contents

Exploring Latency and Power

by Michael Nacht and Zachary Davis

More than half a century ago, two distinguished students of strategy among nations examined the evolution of the weapons and tactics of warfare, concerned not with "the great generals of history, but with the application strictly of intelligence to the problem of war—of intelligence not as it sometimes expresses itself on the battlefield, but in quiet studies or laboratories far removed."[1] The authors traced the advent of gunpowder and its effect on artillery and naval power; the crucial role of the British scientific community in the development of radar, that was central to their triumph against the Germans in the Battle of Britain; and, of course, the impact of nuclear weapons that made "the importance of protecting adequately the main retaliatory striking force of the nation. . .second to no other security question."[2]

What this study and some others have in common are a focus on nation-states, in particular the "great powers," and how political and military leaders were (and are) sometimes very slow to appreciate how technological innovation could provide enormous advantages on the battlefield.[3]

We are witnessing today how some technologies—notably armed drones and offensive cyber operations—have become central to President Obama's national security strategy with respect to counterterrorism in the first instance and degrading the Iranian nuclear weapons development program in the second.[4]

The perspective of this volume is somewhat different. First, we note that the nuclear age, which Bernard Brodie characterized as being ushered in by the "absolute weapon" in 1946, has now been joined by the information technology revolution, the synthetic biology revolution, and other technological advances that are bewildering in their complexity, uncertain in their path to deployment, and difficult to assess in terms of individual and collective impact. Second, these advances are not solely in the hands of the great powers, but are accessible to medium powers, failed states, nongovernmental organizations that may or may not be in the service of governments, terrorist groups seeking to overthrow established governments, criminal cartels motivated to utilize these technologies for financial gain, and individuals and small groups who are developing advanced technologies in part to further their definition of preferred societal goals.[5]

The increasing complexity of the international system combined with the power and accessibility of advanced technologies demands fresh thinking about the concept of security. We seek to understand how

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[1] Bernard and Fawn M. Brodie, "*From Crossbow to H-Bomb*," Revised and Enlarged (Bloomington, IN: Indiana University Press, 1973), 13.

[2] Ibid., 267.

[3] Two recent especially valuable studies are Max Boot, *War Made New: Technology, Warfare and the Course of History—1500 to Today* (New York: Gotham Books, 2006) and P. W. Singer, *Wired For War: The Robotics Revolution and Conflict in the 21st Century* (New York: The Penguin Press, 2009). The former offers a detailed 500-year history of the impact of technology on warfare; the latter looks at one technology—robotics—and predicts that it will change not only how wars will be fought but the "politics, economics, laws and ethics that surround war itself." In addition, the classic *Makers of Modern Strategy from Machiavelli to the Nuclear Age*, edited by Peter Paret, Gordon Craig, Felix Gilbert (Oxford, U.K.: Oxford University Press, 1986) is a valuable historical account of the influence of technology on military strategy.

[4] See David Sanger, "*Confront and Conceal: Obama's Secret Wars and Surprising Use of American Power*," (New York: Crown Publishers, 2012), especially 188–225 and 243–270.

[5] In this last category, note for example the activities of billionaire entrepreneur Elon Musk. He has established Tesla Motors with the goal of not only manufacturing electric cars but also putting the contemporary automobile industry dominated by the internal combustion engine out of business, motivated in part by his concerns about global climate change caused by human use of fossil fuels. Moreover, whereas NASA has eschewed manned space flight, Musk has established SpaceX that has built space launch vehicles with the ultimate goal of creating a permanent human presence on Mars.

these multiple and seemingly uncoordinated technological advances could affect the relative power among states and possibly nonstate actors.

In this study we are looking "over the horizon" at technologies not yet mature and fully deployed. And we are studying "power" in terms of both traditional "hard" variants such as military and economic instruments, and "soft" variants such as diplomacy, culture and history.[6] Our approach is broad and inclusive in the hope of capturing some of the major trends that are reshaping the world—for better and for worse.

At the core of the volume is the study of strategic latency. The dictionary tells us that something is "latent" if it is dormant, untapped, concealed, undeveloped, or unfulfilled. "Strategic" is identified with long-term or fundamental changes to the environment. So strategic latency concerns, for our purposes, technological advances—still underdeveloped—that once fully materialized could fundamentally change the power environment among key international actors.

The aim of the editors was to recruit specialists from a variety of fields and let them "run free" in terms of their own understanding of strategic latency and what that means for their specific subject.

This book consists of three main sections, with an introduction for each summarizing the key findings for each chapter. In the first section, we devote considerable effort to defining what we mean by strategic latency. How to think about it conceptually is the subject of Ronald Lehman's opening chapter. Zachary Davis addresses how government can respond to and defend against its harmful effects. Joseph Pilat then examines what we can learn from our experiences with a previously latent technology—nuclear weapons.

The second section consists of a series of technology cases. We have chosen not to examine obvious cases from the recent past or those that are now the subject of considerable attention such as stealth technology, genetic engineering, cyber weapons, big data, quantum computing, drones, and other emerging technologies that merit further study. Instead, Robert Yamamoto assesses why lasers have not yet realized their military potential. Robert Manning looks at robotics in a broader perspective. Richard Silberglitt explains how technology forecasting could change the world. Finally, Banning Garrett gives an optimistic assessment of the benefits of additive manufacturing.

The third section is a group of country case studies intended to reveal how cultural and historical differences shape latent technology activities. Tai Ming Cheung focuses on China's scientific and technological innovation. Zev Winkelman and Michael Nacht shed light on Turkey's extensive activities, with emphasis on nuclear technology. Carolyn Chu and Michael Nacht place Japan's technological capabilities in perspective, again with nuclear emphasis. In the final chapter, Stephanie Shipp and her colleagues provide a comparative assessment of the technological innovation processes in Russia, the Republic of Korea, and Brazil.

Dr. Davis and Professor Nacht then offer tentative conclusions about what has been learned and propose next steps for developing an analytic framework for strategic latency.

Finally, four points require emphasis. First, edited volumes are always vulnerable to the criticism that the chapters are "uneven." The unevenness of this volume is intentional. The authors were encouraged to offer their expertise and insights on this subject in their own manner and were not constrained to fit their analyses to a particular template or set of questions. Indeed, the concept of strategic latency is itself a work in progress open to interpretation. Readers are encouraged therefore to select those topics of interest to them, formulate their own ideas, and not necessarily seek a unifying formula throughout the volume.

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[6] The term "soft power" was coined and developed in Joseph Nye, "*Soft Power: The Means to Success in World Politics*," (New York: Public Affairs, 2004).

Second, the editors' intent is not to produce the "last word" on the subject of "strategic latency and world power" but to be among the first. We seek to stimulate a thoughtful debate on the subject, not to end discussion or provide a definitive answer to questions about which technologies or states are most important or ripe for "breakout." Indeed, readers will detect a wide range of expectations among the chapters, ranging from an optimistic perspective about the benefits of emerging technologies outweighing the risks, to a more gloomy outlook about the prospects for military applications. This dichotomy of views about the uses of technology reflects the linkage of strategic latency to international relations theory and studies of war and peace.

Third, we were not able to address many important technologies or key nonstate actors. These may be subjects for subsequent work.

Four, all chapters are based solely on unclassified sources available in the open literature. Readers with access to classified information concerning particular technologies or countries should bear in mind this constraint in reviewing the material presented.

We hope that the evidence and analyses presented in these chapters leads to considerable additional work in this important and underresearched field and look forward to extensive interactions with our readers.

What Is Strategic Latency? an Introduction

by Michael Nacht

Section 1 of this volume presents the core definitional and conceptual elements as well as some of the key policy issues associated with strategic latency. Dr. Ronald Lehman, in many ways the founding father of the concept, presents a rich and detailed analysis of what he terms "a package of diverse technologies that can be deployed quickly, often in new ways, with limited visibility that could have decisive military and geopolitical implications." He notes that these are transformative, not incremental, in their impact. Lehman's chapter raises many difficult definitional issues about the limits of the concept of strategic latency, while at the same time laying the foundation for systematic analysis of latency and related phenomena. He explores possible modes of response and ends with key questions for further exploration.

Dr. Zachary Davis presents a sophisticated discussion of how to defend against strategic latency when it poses a threat to national security. He notes that governments no longer control the research and development process and that the proliferation of players and technologies makes the problem of detection immensely challenging. Davis addresses means of deterring military aspects of strategic latency and defeating it when necessary. Finally, he examines the means required to sustain leadership in science and technology to ensure against strategic surprise.

Dr. Joseph Pilat looks specifically at the case of nuclear latency and the development of nuclear weapons. He explores the governance problem from the 1946 Acheson–Lillienthal report to the Nuclear Non-Proliferation Treaty to contemporary challenges in the nuclear field. He notes, in particular, the inherent tensions between the secrecy of nuclear weapons development and the transparency required to verify arms control and disarmament agreements.

Together, these chapters provide the intellectual, historical and policy context for understanding strategic latency.

Unclear and Present Danger: The Strategic Implications of Latent, Dual-Use Science and Technology[1]

by Ronald F. Lehman

Strategic Latency in a Nutshell

Technologies are multiplying, advancing, and spreading rapidly around the globe. Most technology has peaceful applications, but any technology can be dual-use to the degree that it enhances weapons or supports the use of force. Military organizations, police departments, terrorists, and even common criminals all seek technology that can make them more effective. The application of most dual-use technologies does not produce strategic or tactical surprise. Nor does it routinely disturb power relationships within and among the countries of the world. Nevertheless, many nations and nonstate actors, legitimate and outlaw, do have access to diverse portfolios of technologies whose applications could significantly impact international security.

Governments, industries, groups, or individuals usually acquire technology pioneered and provided by others, but the probability of strategic surprise is increased by options to become self-sufficient and to package diverse technologies quickly, often in new ways and without visibility. This condition of strategic latency has long existed, but its larger scope today is not widely understood, and the potential for strategic surprises may be growing. A better picture of the strategic potential of latent dual-use technologies may help reduce dangers by providing the time, information, strategies, and capabilities necessary to respond effectively.

What Do We Know? What Do We Need to Know?

The issues associated with strategic latency are not new. Classic strategic and intelligence analysis includes technology in military threat assessments. Examination of potential proliferation paths always focuses on the spread of dual-use technologies to acquire weapons of mass destruction (WMD). Many of the activities now highlighted through the international security prism of strategic latency, such as outsourcing, offshore production, agile manufacturing, and just-in-time inventories, in conjunction with the global technological talent base, have been scrutinized in detail for decades by scientists, industry, economists, and investors.

Strategic latency is similar to globalization, with which it is tightly linked. Globalization and the advance of science and technology (S&T) at the end of the 19th century were remarkable compared with the previous one or two centuries. However, globalization today is even more intense and diverse—so much so that the study of globalization has become an interdisciplinary specialty. And so it is with strategic latency. The advancement and wider accumulation of dual-use technology is worthy of study itself. In bringing together such different perspectives as military intelligence, nuclear safeguards, bio-security, export controls, arms control, disarmament, verification, information technology, cyber operations, innovation economics, business management, foreign trade, intellectual property law, investment strategies, science culture, education, development, and ethics, we may not only gain new insights into each of those fields, but we may obtain transcendent insight into the dynamics of the contemporary world. Along the way, we should test ourselves for inappropriate stereotyping and mirror-imaging in our assessments of others.

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[1] This chapter is based upon remarks that were originally prepared for delivery by the author at the National Intelligence Council Workshop, "Strategic Latency and the S&T Challenge: Understanding Emerging Technology Threats & Surprises," McLean, VA, November 2–4, 2010. The workshop was cohosted by Larry Gershwin, National Intelligence Officer for Science and Technology, the National Intelligence Council; Lawrence Livermore National Laboratory (LLNL); and Los Alamos National Laboratory (LANL), with participation from other departments and agencies of government, other national laboratories, and outside experts. Subsequent workshops were held at LLNL on September 13–14, 2011, and at LANL on April 30–May 1, 2012.

Before building up expectations about what we may learn from the study of the strategic latency associated with widespread, dual-use technology, we should first acknowledge that we have many questions for which answers are not yet clear. Data are available, but the dynamics are complex. Case studies are needed to dig deep into the substance of strategic latency. At the same time, a broader framework would also be helpful to prioritize our research and organize our findings. A sound analytical framework would help create a sense of priorities and proportion to avoid dysfunctional dynamics such as those in Aesop's classic fable, "The Boy Who Cried Wolf" or modern fables such as "Henny Penny" (Chicken Little) with its cries of "the sky is falling."

To establish such a framework, we need to ask useful questions that help us understand the magnitude of the problems we face. For example, to what degree is each of the following hypotheses true? (1) Weapons and technologies related to them are advancing and spreading widely, (2) lead times for exploitation by more actors are shrinking significantly, (3) intelligence information and awareness are fuzzy (4) vulnerabilities exist that increase the risk of leveraged threats, (5) players with deadly motivations exploit latency, (6) challenges to timely response are significant, (7) norms and goals are unclear, (8) enforcement options may be unattractive or ineffective, (9) tipping points are approaching, and (10) consequences are strategic in that they alter international security relationships in important ways. Note that we are asking, "To what degree are these hypotheses true?" We want to be able to gauge and compare significance.

Concrete examples in support of each of these hypotheses have long existed, but counter examples can also be found. Casualties in wars between nation-states escalated in the first half of the 20th century as dual-use technology was exploited to create increasingly destructive weapons. During those same decades, even greater scientific revolutions occurred in quantum mechanics and nuclear physics. Yet, in the second half of the century, casualties from war declined remarkably.

Does strategic latency always mean that everything is accelerating? No nation since the Trinity nuclear test has thus far acquired nuclear weapons as quickly as the U.S. did. Can small groups or individuals do us greater harm more easily as our interconnectedness exposes us to attack? Teenage hackers in the developing world attack the databases of global financial institutions, the archives of defense industry, and the private accounts of individuals, causing great anguish, considerable cost, and substantial monetary loss. On the scale of modern economies, however, their impact is widely perceived as vandalism, not yet the mortal threat projected by some experts.

One can debate whether the advance and spread of technology in the electronic and digital age has had greater strategic significance in our times than the advance and spread of technology had during the industrial revolution. Certainly, the defeat of the Russian fleet in the Tsushima Straits in 1905 by a Japanese Navy demonstrated a century ago that newcomers could use technology to quickly catch up and surpass and thus alter history for decades to come. Neither the Russian Revolution nor the Pearl Harbor attack was made inevitable by the surprisingly stark outcome of the Russo-Japanese War, but the contribution is clear.

Some contemporary questions meant to clarify our thinking about strategic dual-use latency do not have obvious answers. For example, biotechnology is globalizing at a rapid pace. Centers of excellence in the life sciences exist in many troubled regions. Yet, evidence of the spread of bioweapons programs is limited, and several attempts by fringe groups to use bioweapons failed or were small. Experts are divided over how likely we are to face a major bioterror threat. For the most part, terrorist groups have used the weapons they know, namely, high explosives, guns, and knives. As the historian Lynn White documented in his classic study of medieval advancement, "As our understanding of technology increases, it becomes clear that a new device merely opens a door; it does not compel one to enter."[2] Why states or groups don't

[2] Lynn White, Jr., *Medieval Technology and Social Change* (Oxford: Oxford University Press, 1966), 128.

develop or, when developed, don't exploit available dual-use technologies is as important an area of study as identifying what paths they might take.

Many other questions can be used to elaborate our concept of strategic latency further to give us both qualitative and quantitative measures of merit. The former might categorize a risk; the latter might measure it more precisely. For example, when a country acquires the ability to enrich uranium or separate plutonium, that country, whether it is a member of the Nuclear Non-Proliferation Treaty in good standing such as Japan or suspected of being in violation such as Iran, often finds itself on lists of those with a nuclear weapons potential. Analysis of the sophistication of that technology, the size of facilities, and its relationship to other capabilities sometimes leads to attempts at more precise guestimates as to how long it would take to realize that capability if and when a decision were made.

Before the Desert Storm campaign to drive Iraqi forces out of Kuwait, public statements suggested that it would take about 10 years for Saddam Hussein to acquire nuclear weapons. After the war, discoveries by the United Nations Special Commission inspectors caused speculation that Iraq may have been closer. It is common today for experts to say that with its extensive, advanced nuclear and related technologies, Japan could build nuclear weapons in less than a year if it ever made such a decision. As Iran builds up the number of its gas centrifuges and improves their quality, the estimate of the number of years until Iran could have a nuclear weapon has declined from many to few. Thus, timelines for achievement are an important element in thinking about strategic latency.

The qualitative and quantitative analysis of latent strategic capabilities can overlap. Because North Korea had defueled an unsafeguarded reactor in 1989, the Central Intelligence Agency of the U.S. stated in 1992 that Pyongyang might have enough nuclear material for one or two nuclear weapons. It was a qualitative measure of a threshold or milestone achieved for which a quantitative measure was not a timeline but rather a possibility of occurrence. A sound framework for the study of strategic latency that allows for quantifiable measures of merit would be very valuable. Could such a framework be articulated? Could it provide measures of overall strategic latency? Could it enable us to quantify specific risks associated with latency? Could it permit us to evaluate the true strategic significance of a latent military possibility in the context of real world dynamics?

Certainly in an attempt to gauge overall strategic latency, we could look at gross statistics such as research and development as a percentage of gross domestic product. We could look at outsourcing, trade networks, the movement of capital, and the migration of technological talent. Many such gross measures of potential for strategic latency are interesting, but their utility is limited. How can we measure the significance of specific technological latency in a strategic context? In looking at nuclear proliferation concerns, for example, we can look at a country or a corporation and count its nuclear reactors or nuclear engineering departments or nuclear physicists or fissile material. A systems analysis might even reveal an estimate of the time it would take for that entity to produce a nuclear weapon if a decision were made. Strategically, however, what does it really mean? And how do we evaluate specific possibilities in context?

In the end, understanding the policy implications of a particular latent technology requires better calibration of specific risks along different paths and timelines. Latent dual-use technologies can increase the destructiveness or effectiveness of weapons and those who use them, but they can also increase the likelihood that such a threat will emerge and surprise us with its rapidity. Both consequences and probabilities must be evaluated, with multiple possibilities or scenarios in mind. How we think about consequences and probabilities deserves some further discussion because it is at the foundation of what constitutes "strategic."

"Perverted Science": "Our Final Hour"[3] or Our "Finest Hour"[4]

Strategic latency may be of greatest concern in the proliferation of WMD, weapons that raise the specter of what Sir Martin Rees called "our final hour."[5] Nevertheless, when in 1940 Winston Churchill said to the people of his island nation that "their finest hour" was to prevent the world from sinking "into the abyss of a new Dark Age made more sinister, and perhaps more protracted, by the lights of perverted science,"[6] he was speaking of the beginning of a second world war. Nuclear weapons had not yet been created. Although biological and chemical weapons were used in previous wars, the onslaught Churchill expected was from what we now call "conventional munitions," indeed crude weapons by today's standard. Although bullets, artillery, and "dumb bombs" that would be familiar to any veteran of World War II are still manufactured and deployed in large numbers, "conventional" today often means self-propelled, self-guided, precision, or target-sensing weapons with shaped-charges or other advanced kinetic devices or explosives.

In considering risks associated with latent technologies, where should we draw the line between what is "strategic" and what is not. Should we confine ourselves to WMD? Should we include other weapons? Should we include means of delivery? Should we include weapons of "mass disruption" such as cyber warfare? Should we include C^3RSI?[7] Should we include technologies that alter economic power or political influence? If we define "strategic" as having the capacity to significantly alter international security, then all of these may be legitimate candidates. Certainly, latency is of interest in a number of spheres and can apply to possibilities that we would not consider strategic in slightest. Perhaps priority should be given to those latent technologies that present the greatest risk to our national interests, in particular those that may present us with sufficient surprise that our response might not be adequate.

If strategic latency is not all about weapons, nevertheless, weapons potential is embedded in the concept. All weapons are not equal, and all weapons latency is not the same. Consider the idea of WMD. Because nuclear weapons are capable of destroying cities, with their concentration of population and infrastructure, nuclear weapons are the most widely recognized WMD, no matter what the possibility of their limited or discriminate use.

Not everyone agrees what biological warfare agents, if any, should be labeled as WMD. The history of plagues and pandemics makes clear that disease can alter history, but in the modern age of epidemiology, vaccines, antibiotics, and modern emergency medicine, doubts have been raised about how effective human-initiated disease weapons would be. Difficulties in dispensing agents, lack of interest by some potential users, and belief in countermeasures cloud the issue. As we have seen, past attempts to use biological weapons have been crude, and uncertainty exists as to whether future use of such weapons would likely rise to the level of a WMD. Given that nations have developed extensive biowarfare capabilities and given that advances in synthetic biology may make more dangerous pathogens or toxins

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[3] Taken from the title of Sir Martin Rees, *Our Final Hour: A Scientist's Warning: How Terror, Error, and Environmental Disaster Threaten Humankind's Future in this Century—On Earth and Beyond* (New York: Basic Books, 2003).

[4] Taken from the title of Winston S. Churchill, *Their Finest Hour: The Second World War*, Vol. II., 1949.

[5] Rees, *Our Final Hour,* also discusses threats to mankind other than weapons that are by-products of the exploitation of technology, such as climate change, for which technology may also provide solutions.

[6] "But if we fail, then the whole world, including the United States, including all that we have known and cared for, will sink into the abyss of a new Dark Age made more sinister, and perhaps more protracted, by the lights of perverted science. Let us therefore brace ourselves to our duties and so bear ourselves that, if the British Empire and its Commonwealth last for a thousand years, men will still say, 'This was their finest hour.'"—Winston S. Churchill to House of Commons, June 18, 1940.

[7] Command, control, communications, reconnaissance, surveillance, and intelligence.

more easily available, the majority view today is that biological weapons are WMD and that the threat is real. Some believe that artificial creation of virulent, drug-resistant strains of infectious diseases could become the most dangerous WMD.

Acronyms such as "NBC," "CBW," and "CBRNe"[8] remind us that chemical weapons, the "C," have long been lumped together with WMD. Not everyone agrees with that judgment, although recent attacks in Syria may give pause. Huge stockpiles are necessary to cause mass casualties. Methods of dispensing can be unreliable. Variables in weather, terrain, and infrastructure seriously impact effectiveness. Countermeasures can be available. Some experts believe that chemical weapons do not meet a sufficiently demanding standard of mass casualties in a short period of time to be considered WMD. The same judgment is made even more often about radiological weapons, electromagnetic-pulse weapons, cyber weapons, advanced conventional munitions, and especially improvised explosive devices. Whether considered possible WMD or weapons of mass disruption or just weapons, they are not considered as threatening as nuclear or perhaps biological weapons. If they do not today meet a consensus definition of WMD, might they in the future with technological advances? And if they are unlikely to ever meet a strict definition of WMD, could they nevertheless be "strategic" in their international security consequences?

Should we draw the line for strategic latency at the latent potential for WMD, or should we draw the line elsewhere? In the September 11, 2001, attacks on the World Trade Center and Pentagon, box cutters were used to commandeer airliners that became human-guided missiles attacking heavily populated buildings, causing casualties on the scale of the attack on Pearl Harbor. The consequences were catalytic for two wars, prompting restraints on trade and travel, compromises on privacy and civil liberties, tremendous economic burdens, and distortion of research and development to deal with existing threats and those that might come about because of latent technology. Should this experience cause us to broaden our scope of interest in strategic latency beyond either narrow or broad definitions of WMD?

Whether or not we consider the highly leveraged potential impact of chemical, biological, radiological, nuclear, electronic, cyber, advanced conventional, or other technologies on societies as within the realm of strategic latency, all of these fields have similar dynamics. Nuclear weapons are not as easy to acquire as nerve gas, which may not be as easy to acquire as some biological agents, which are not as easy to acquire as some explosives, or Web-connected computers, or box cutters, but all are becoming easier, quicker, cheaper, more widely disseminated, and more dangerous. Many enabling developments in technology, industry, and society are similar. Advanced systems are often far more difficult to achieve than crude and early-generation systems, but advanced capabilities may not be necessary to pose a strategic threat. Even so, some very advanced capabilities are becoming more accessible to more actors of concern. We need to draw the line somewhere, but clearly the study of strategic latency should probably consider more than WMD latency.

Risk is often characterized as the product of consequences and probabilities. In the 20th century, which saw the use in war of chemical, biological, and nuclear weapons, WMD use was generally considered a high-consequence, low-probability event. The worst that could have happened in that century did not happen. Nevertheless, well over 150 million people died in the wars and civil wars between 1900 and the beginning of the new millennium. Nuclear, chemical, or biological weapons killed few of those people. Simple bullets or even machetes killed millions.

8 Nuclear, chemical, and biological (NCB); chemical/biological weapons (CBW); and chemical, biological, radiological, nuclear, and enhanced conventional explosives (CBRNe).

Nevertheless, the advance of weaponry made possible by the industrial age made killing more efficient. Sadly, it also took war more decisively to civilian populations.[9] The greatest potential danger may have been present in the high-consequence, low-probability scenarios, but the greatest actual loss of life was in the low-consequence, high-probability scenarios. Still, the loss of life to war, especially wars between nations, has been declining. Thus far, that pattern has continued in the 21st century, but will it always remain so? There are reasons for hope, but also reasons for concern.

The end of the Cold War has dramatically reduced the number of weapons in the superpower arsenals. Likewise, the explosive power of nuclear weapons, cumulatively and in individual weapons, has dropped dramatically. The highest-consequence events possible in the Cold War are no longer in the mix. Still, the destructive power available to nations remains large, and more nations are acquiring and increasing their destructive power albeit at levels far below that of the Cold War years.

Today more players are exploiting strategic technologies for military purposes, which is a cause of some concern. That many of the new players are to be found in highly troubled regions is of greater concern. At the risk of some oversimplification, the trend in recent years has been for the probability and consequences of the worst possibilities to go down. However, as dual-use technology spreads into troubled regions, the consequences of high-probability events go up. Overall, net risk may have gone down. Certainly, the percentage of populations killed in violence continues to drop, but the curve is not smooth. Large-scale violence may be sporadic, but it drives up losses and reminds us that worse may be possible. Growing access to latent, dual-use technologies may accelerate this trend or make it more difficult to assess or counter.

With the end of the Cold War blocs and the rise of terrorism, much of the concern about the spread of WMD technology has moved toward the outlaw state and the nonstate actor. The stateless or transnational WMD terrorist group or even a WMD "Unabomber"[10] has become a major international security preoccupation. However, reality is more complex. Confrontation between NATO and the Warsaw Pact, while never the sole security concern in the Cold War, is no longer an issue because the Warsaw Pact and the Soviet Union have disappeared. Alliances and coalitions remain important, however, as reflected in the deployments of international forces to Afghanistan or Kosovo where the concerns are regional, secular, and ethnic, and especially the international terrorism such conflicts may spawn. As developments in Lebanon, Gaza, and Syria reflect, however, nations may organize to counter technologically empowered terrorists who are technologically empowered by governments that do not consider these same groups to be terrorists.

Even to speak of the nation-state as the actor in the exploitation or misuse of latent, dual-use technology is much too simple. Advanced, free-market democracies often discover that businesses, organizations, individual citizens, and sometimes even legitimate governments themselves aid the spread of dual-use

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[9] For data and analysis, see Ronald F. Lehman, "Agriculture and the Changing Taxonomy of War," in M. Taeb and A.H. Zakri, eds., *Agriculture, Human Security, and Peace: A Crossroad in African Development* (West Lafayette, IN: Purdue University Press, 2008) 11–34.

[10] "Unabomber" was the name given to the then unknown perpetrator of 16 letter bomb attacks that killed three people and injured nearly two dozen others. The Unabomber demanded that unless his "Manifesto" describing the evils of highly organized, advanced technology societies were published, he would attack again. It was published. Its opening sentence is "The Industrial Revolution and its consequences have been a disaster for the human race." See http://www.washingtonpost.com/wp-srv/national/longterm/unabomber/manifesto.text.htm. The Unabomber was ultimately identified as Theodore Kaczynski, a mathematician who graduated from Harvard, received his Ph.D. at the University of Michigan, and was an Assistant Professor briefly at the University of California, Berkeley. Kaczynski is serving a life sentence. Although the Unabomber was often described as an anarcho-primitivist, ironically, the name Unabomber has become synonymous with the idea that even a lone individual could exploit technology to significantly damage or disrupt an advanced society.

technology to parties of concern. The picture is more troubling still when one considers failing or failed states, quasi-states not widely recognized, lawless regions such as the those along the Afghan–Pakistani border, state surrogates, state–private hybrids, state-sponsored terrorists, state-assisted or -tolerated terrorists, and unauthorized actors within governments. As the A. Q. Khan nuclear proliferation network demonstrated, actual behavior may overlap many categories of relationships to government.

Support by one or more governments was once the major way in which terrorists or insurgents obtained advanced dual-use technology. It may still be. Certainly the past transfer of mortars, rockets, shoulder-launched antiaircraft missiles, drones, and advanced shaped charges to nonstate actors in the Middle East and Afghanistan underscores the significant role that government-related actors play. The prominent role of scientists, engineers, and even medical doctors in terrorist groups, however, has highlighted that not all terrorists are technically primitive. The greater ease of access to dual-use technology linked to globalization of science and consumer economies has resulted in greater sophistication of nonstate-aided terrorists, ethnic and communal combatants, affinity groups, and violent transnational entities down to the cell and individual level. Dual-use technologies in multinational companies, the growing private security industry, and criminal activity complicate tracking these developments even when no political, ideological, or social agenda is involved.

When, as in the case of airliners, ships, or nuclear reactors, targets themselves accessible to many people become the weapons, the analysis of strategic latency gains yet more complexity. When the application of the dual-use technology is less against military targets than against societies or individuals selected because they are part of those societies, the challenge of strategic latency becomes even more intense if by "strategic" we mean more than WMD. It may not be possible to capture all of these dimensions in a single research question, but the common ground suggests something similar to the following:

To what degree are more potential and capability to acquire, deploy, and use more WMD, mass disruption, or other strategically leveraging technology becoming more accessible to more players (state, nonstate, and hybrid) for more ambitious goals? More delivery options and more destructiveness aimed increasingly at citizens and interconnected societies may lead, for those threatened, to more mismatch between the lead times of the threats and the reaction times for prevention, mitigation, or consequence management.

There is a powerful temporal dimension to this challenge. The concept of strategic latency invokes not only a possibility but also a timeframe for that possibility.

…the present is pregnant with the future… —Gottfried Wilhelm Leibniz[11]

The temporal dimension in the word "latency" invites the use of that word rather than other words to describe the strategic problem of dual-use technology that is quickly becoming more easily and widely available. No one definition of latent or latency exists, and it is possible to find definitions of latent that minimize the temporal dimension, that is to say, the dimension of time. Consider a definition that suggests when something is latent, it is "potentially existing, but not presently evident or realized."[12] A possible sequential step is implied, but not much is implied about time. Indeed, an important element of latency is that the potential is not always realized. Not all possible dual-use technologies are exploited for military applications, or perhaps any applications.

Part of the richness in the concept of "latency" is that it has many slightly different, nuanced definitions that provide insights into the problem of strategic technology. Indeed, a major advantage of introducing a

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[11] Gottfried Wilhelm Leibniz, *La Monadologie* (1714), paragraph 22. For English translation, see Leibniz, *The Monadolog,* translated by George MacDonald Ross, 1999.

[12] http://www.thefreedictionary.com/latent, accessed March 23, 2012.

broader concept such as latency into the study of military technology, proliferation, arms control, disarmament, the history and sociology of science, counterterrorism, and globalization is that it may give us more understanding of each field and also overlapping interactions. A new vocabulary may encourage different perspectives and advance knowledge in areas that seem staid.

"Latency" evokes different related concepts, for example, of something pending, perhaps suspended, or in abeyance.[13] Latent technologies emerged because someone thought they would have a use. The intended use may not be the ultimate use. In fact, some technologies may find no economically viable market, now or ever, and yet may be of security concern. Latency thus suggests some embedded level of potential or an inherent possibility not yet realized. A capability may be dormant, but many latent technologies are not particularly dormant. Much activity is taking place around them, but they are not being applied in an area of significance, much less in an area of strategic significance.

Even when used without a temporal dimension, latency is tense with the idea that something could happen. Definitions imply something that is "almost, but not yet active"[14] or that something could be obtained or happen soon. Latency has a number of technical definitions that reinforce this preparatory aspect. For example, in biology latency may be "lying dormant or hidden until circumstances are suitable for development or manifestation."[15] In business or economics, latent demand is a "desire that is not currently being satisfied."[16] Some farmers consider a field to be "latent" when the crop will be ready after one more rain. In physics, it is concealed energy or heat that is released or absorbed when temperature and pressure are constant, but a phase change occurs, as when water goes from liquid to solid or gas.[17] The concept of a potential transformation or phase change that is starkly and qualitatively different and less incremental captures the essence of what most experts are looking for when they speak about "strategic latency."

In thinking about *strategic* latency, however, the "when" is almost as important as the "what" for at least four good reasons. First, if the potential for dramatic change is not within the time horizon of concern, the latent potential is difficult to call strategic no matter how big. In five billion years, as the Sun runs out of fuel, Earth can expect to be destroyed. Few people lose sleep over that. On the other hand, major economic, energy, environmental, and security issues that may play out over many decades or even a century do become strategic because their impact is within the time horizon in which we must make decisions to forestall unwanted consequences. This observation leads naturally to our second reason that the temporal dimension of latency is important: namely, the lead time needed for effective response. Much of our interest in identifying latent conditions that could be strategic stems from our need to prepare for preventing or mitigating unwelcome developments and encourage or exploit those we desire. This suggests

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13 See for example, *The American Heritage® Dictionary of the English Language*, Fourth Edition, (Boston, MA: Houghton Mifflin, 2000). la·tent (lᵃt'nt)adj. 1. Present or potential but not evident or active: latent talent. 2. Pathology. In a dormant or hidden stage: a latent infection. 3. Biology. Undeveloped but capable of normal growth under the proper conditions: a latent bud. 4. Psychology. Present and accessible in the unconscious mind but not consciously expressed. n. A fingerprint that is not apparent to the eye but can be made sufficiently visible, as by dusting or fuming, for use in identification. [Middle English, from Old French, from Latin latns, latent- present participle of latre, to lie hidden.] latent·ly adv. Synonyms: latent, dormant, quiescent These adjectives mean present or in existence but not active or manifest. What is latent is present but not evident: latent ability. Dormant evokes the idea of sleep: a dormant volcano. Quiescent sometimes—but not always—suggests temporary inactivity: "For a time, he [the whale] lay quiescent" (Herman Melville). http://www.yourdictionary.com/latent, accessed March 28, 2012.

14 http://www.thefreedictionary.com/latent, accessed March 23, 2012.

15 http://oxforddictionaries.com/definition/latent, accessed March 23, 2012.

16 http://medical-dictionary.thefreedictionary.com/latency+period, accessed March 28, 2012.

17 http://www.britannica.com/Ebchecked/topic/331406/latent-heat, accessed March 23, 2012.

the third reason we care about how long we might have available to respond: to help establish priorities for the allocation of scarce resources and time. The fourth reason is both theoretical and practical. In theoretical analysis, defining something in measurable terms helps clarity. In practice, measuring our ability to increase or reduce the timeline before something latent is actualized can be a management tool or measure of merit.

Some technical definitions of "latency" do have precise temporal measures,[18] and we can see in each of these technical definitions all four of our reasons why a temporal dimension is important to understanding latency. Consider, for example, in computations, latency is the time it takes for a message or data to traverse an information technology system.[19] In recording, latency is the time delay between when a sound is made and when it is recorded or played back.[20] In psychology, latency is the time of apparent inactivity between stimulus and response, or, as in a latent emotion, something unconscious before it is expressed.[21] Biology describes latency as a resting stage during development.[22] In medicine, it is the period of time in which a disease is present without producing symptoms.[23] In industrial engineering, latency is the time one must wait for a necessary component or the "mean time between failures" determined by latent defects.[24]

What does all of this imply for our use of the concept of latency in the strategic environment? Consider, for example, automated, algorithmic trading in capital markets.[25] Such trading is associated with changes in information or with arbitrage strategies to take advantage of different prices for the same item in different markets.[26] Here latency refers both to the conditions that create opportunities and risks and to the measures of lead times and reaction times. Competitors are looking for "latent conditions" that create opportunities, but then seek to have "low latency" in response time so that they do not miss out on an opportunity. The risk is that if their response time is too long, somebody else may have changed the conditions. Timeliness determines how an opportunity is transformed into a risk. Thus, latency can be good or bad depending on what we do and what others do.

Strategic latency can be a condition, a timeline, a strategy, and even a goal. Consider nuclear proliferation. A nation's ability to enrich uranium or separate plutonium may create a latent condition in which that country could exploit its weapons-usable material to develop atomic or thermonuclear bombs. We might measure that condition by describing the percentage of the technical or industrial capability necessary to

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18 http://www.websters-online-dictionary.org/definitions/latent, accessed March 23, 2012.

19 http://searchcio-midmarket.techtarget.com/definition/latency, accessed March 28, 2012.

20 http://www.digitalprosound.com/Htm/Articles/April/Audio_Latency.htm, accessed March 28, 2012

21 Latency has numerous definitions in psychology and psychoanalysis. For example, "existing in unconscious or dormant form but potentially able to achieve expression: a latent emotion." Dictionary.com Unabridged, based on the *Random House Dictionary* (New York: Random House, Inc., 2012), http://dictionary.reference.com/browse/latent, accessed March 23, 2012.

22 http://www.biology-online.org/dictionary/Latency, accessed March 28, 2012.

23 See *Mosby's Medical Dictionary*, 8th edition. (Waltham, MA: Elsevier, 2009), http://medical/dictionary.thefreedictionary.com/latency+period, accessed March 28, 2012.

24 http://www.theriac.org/DeskReference/viewDocument.php?id=196, accessed March 28, 2012.

25 See http://www.securitiestechnologymonitor.com/issues/19_94/-23441-1.html or http://www.intel.com/content/www/us/en/financial-services-it/capital-market/capital-markets-low-latency-trading.html or http://www.techrepublic.com/whitepapers/next-generation-low-latency-front-office-computing-for-capital-markets, accessed March 28, 2012.

26 http://www.investopedia.com/terms/a/arbitrage.asp, accessed March 28, 2012.

produce nuclear weapons that this nation possesses. We might simply note that they have reached this latent threshold, but acknowledge the requirement to meet other thresholds such has having a weapons design or having a means of delivery. Discussions of latency usually focus on qualitative thresholds or conditions such as the ability to enrich uranium. A quantitative threshold may be important as well, such as the ability to produce a given amount of weapons-useable material. The role of technology in qualitative arms races is well understood, but both quality and quantity of technology are important in quantitative arms races, whether the products are dreadnoughts or nuclear weapons.

When asked to measure latency associated with nuclear proliferation, we are often asked about a time line. How long might it take for a given country to acquire nuclear weapons? For the country of concern, achieving some level of latent capability might be a strategy to keep options open. Confining a particular nation to a latent capability short of acquiring actual nuclear weapons may be a goal. The Nuclear Non-Proliferation Treaty (NPT), with its Article III obligations to help nations advance their peaceful nuclear capabilities and its Article II prohibitions on acquiring nuclear weapons, clearly involves managing degrees of latency from the perspectives of condition, timeline, strategy, and goal.[27] Given that the knowledge, technologies, and materials necessary for nuclear weapons are widespread, many proposals to eliminate nuclear weapons are, in essence, proposals for nations with nuclear weapons to move back to a latent state.

Is "Latency" Really the Right Concept?

Latency has many useful definitions, not all of which are consistent, but all of which have utility in highlighting aspects of the dual-use concerns raised by the advance and spread of technology. Other concepts overlap and illuminate the meaning of latency and further illustrate that the use of latency for our purposes is not perfect. Yet, these other concepts such as "virtual" or "dormant" have their own problems. Virtual, for example, has several meanings that can be confusing in the dual-use technology context. Virtual can imply "not real," but many of these technologies are real, both physically and intellectually. Virtual can imply "not authentic," but many dual-use paths to weapons are credible. Virtual can imply "almost, but falls short," which captures some of the meaning of a latent state, but virtual used in this way may leave the false impression of inevitable failure.[28] Likewise, "dormancy" is often a component of latency and captures the important idea of "potential," but dormancy may imply inactivity, which is often not the case in strategic latency. For example, a strategy whose goal is the achievement of strategic latency may be very active even if it also involves restraint.

Even when we chose to use the concept of strategic latency as a tool to gain insight into the dynamics of the advance and spread of dual-use technology, we must use special caution. For example, similar to several other key words or phrases such as "transparency," "to table," or "stakeholder,"[29] latency can be used correctly for one meaning and also imply its opposite. To "increase latency" can mean both to make a lead time longer and to make lead time shorter. If we were concerned about a latent nuclear weapons capability, would we want a potential proliferator to face more time and more steps or less lead time and fewer steps? Would we want to increase the latency, meaning the time for achieving a weapon would be longer, or would we want to decrease the latency, meaning that the time for achieving the weapon would

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27 http://www.un.org/en/conf/npt/2005/npttreaty.html, accessed March 28, 2012.

28 http://www.thefreedictionary.com/virtual, accessed March 28, 2012.

29 "Transparent" can mean you see everything behind a substance, or the greater the transparency of the substance blocking our vision or perception of what is behind it, the less you see it, http://dictionary.reference.com/browse/Transparent, accessed March 28, 2012; "to table" in parliamentary procedure can mean to introduce for consideration or to remove from consideration, http://www.thefreedictionary.com/Table, accessed March 28, 2012; and "stakeholder" can mean someone with a "stake," but the "stakeholder" is a neutral person who holds the stakes, but has no personal interest, http://www.thefreedictionary.com/stakeholder, accessed March 28, 2012.

be longer. Given these two opposite uses of the word latency, discussions of strategic latency tend toward the later approach, but not exclusively. When we speak of growing strategic latency, we tend to mean that more dual-use technologies are available with less lead-time. Care must be taken that the context makes the usage clear.

This examination of alternative definitions of strategic and latency, and alternative concepts, such as "virtual" or "dormant," suggests an obvious question: What dual-use technology does not involve strategic latency? Certainly, any technology can someday contribute to a weapon or system or process that dramatically alters our security. One could examine all technology over the centuries to see how many years, decades, or centuries it took before that technology became part of something that transformed the world. This exercise would provide an interesting history and many modes of analysis similar to what is discussed here. The main difference would be that of response time. We want to look at emerging technologies whose maturing potential, multiple applications, significant consequences, and limited transparency could result in strategic surprise for which our response times today could be too short to prevent adverse consequences.

Nova Methodus[30]

From our evolving concept or definition of "strategic latency," we can begin to construct a simple model of the dynamics. Realization of a latent dual-use potential is basically a product of "intent" and "capability." Does an actor—state, nonstate, or hybrid—want to achieve a certain capability and does that actor have the technology, industry, and resources to advance toward it? Imagine that we have a graph in which intent is measured on the "*x* axis," perhaps as a percentage of maximum commitment to the goal. The "*y* axis" then might be capability, perhaps measured as a percentage of the capability needed to achieve the goal. The goal could be something concise such as a nuclear weapon or more complex such as a high confidence antiaircraft carrier capability. We might observe that the two "variables" in practice may not be independent. For example, as a capability grows, interest and commitment may grow because a path to success becomes clearer. Alternatively, recognition that a capability is near may result in a backlash, reducing net motivation. Likewise, capability may expand or contract under the influence of changes in intent.

With the intent and capability axes placed on a classic *x*–*y* grid—with the origin point connecting them reflecting zero intent and zero capability—one can plot actors on the grid. For example, a nation such as Japan may be toward the upper left reflecting great capability to acquire nuclear weapons but weak intent to do so. A terrorist group such as Al-Qaeda might have a very high measure of intent but minimal capability. It would be graphed toward the lower right part of the grid. Other actors, be they governments, government-related entities, companies, groups, or individuals, could also be plotted.

A position on the graph might not be stable. For example, suppose intent were measured by motivation to acquire minus inhibitions against acquiring. This calculation might produce a vector showing net movement of intent along the *x* axis. The vector for capability might be calculated by measuring access to technology and resources minus limitations on such assets. Thus, from any point reflecting the current location on the grid of any actor, both vertical and horizontal vectors would show growing or declining capability and increasing or decreasing intent.

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[30] "New Method," taken from the original Latin title of Gottfried Wilhelm Leibniz's article presenting differential calculus, *Nova methodus pro maximis et minimis, itemque tangentibus, quae nec fractas nec irrationales quantitates moratur et singulare pro illis calculi genus* (in *Acta Eruditorum*, 1684), http://www.abebooks.co.uk/Nova-methodus-pro-maximis-minimis-itemque/5274518363/bd, accessed March 28, 2012.

The product of the two vectors might be a third vector arrow in any direction showing net direction and force for each actor over time toward or away from a particular achievement. For example, if an actor had increased both its interest in nuclear weapons and its capabilities, the net vector might be a long arrow moving toward the upper right corner, closer to achieving a capability. Countries such as Sweden and Switzerland, who had nuclear weapons programs, may have seen capabilities increase but intent decline significantly. The net vector over time might be toward the upper left corner. Iran may have seen both capability and intent increase and over a given period of time. Thus, the arrow reflecting Iran would move toward the upper right corner. One can imagine that some combination of more emphatic intent and greater technical capability would lead along a vector that would ultimately cross a threshold of capability.

Whether we use this simple model or some other, our goal is to see relationships, dynamics, and movement. Changes in latency differ in different contexts. Actors can differ and morph from state to nonstate. Entities can be large or small, or even individuals. Time frames on the scale of millennia or even centuries may be too long for looking at strategic latency, but decades, years, and months seem central. In the context of tactical action, days, hours, and even minutes are of interest, and in the electronic and cyber world, seconds may matter. These shorter intervals may seem of less interest to our study of strategic latency, but weapons and information technology systems that operate quickly can have strategic implications.

Our simple graph or model might look at capability as a measure of how advanced is an actor or how far the actor is from achieving a threshold. The measure of capability could be in time, percentages, qualitative steps, or some other unit. The threshold might be qualitative, as in creating a nuclear weapon, or it might be quantitative, as in acquiring parity. In our work on strategic latency of dual-use technology, understanding the implications of the technology is fundamental. The variety of technology available today and in the actionable future is tremendous. Interdisciplinary synergism seems far greater than in the past. Synthetic chemistry and biology, genetics, nanotechnology, new materials, cyber and information technology, microelectronics, robotics, photonics, quantum mechanics—all these and many more—provide huge inventories of ideas and innovation.[31] Any attempt to evaluate strategic latency will have to examine case studies of how specific technologies interact with each other and with the world around them.

At the level of our simple model, however, grouping technologies into general categories that reflect how they affect strategic latency is useful. Here is one approach:[32]

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[31] For a tour of the horizon of the multidisciplinary synergy, diversity, and possibilities in science and technology, see, for example, *The Scientific Century: Securing our Future Prosperity* (London: The Royal Society, 2010), in particular the chart on page 41 mapping interdisciplinary cross-referenced journal articles,, http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2010/4294970126.pdf, accessed March 29, 2012.

[32] The author presented a similar discussion at greater length elsewhere; see Ronald F. Lehman, "Future Technology and Strategic Stability," in Elbridge Colby and Michal Gerson, eds., *Strategic Stability: Contending Interpretations* (Carlisle, PA: Strategic Studies Institute, Army War College, 2013).

- *Impossible science*, such as Sir Arthur C. Clarke's wormhole camera looking into the past.[33]
- *Theoretical science*, such as an anti-matter bomb.[34]
- *Breakthrough S&T*, such as directed-energy weapons and nanotechnology.
- *Extrapolated S&T*, such synthetic biology and cybernetics.
- *Monopoly technology*, such as invisibility or "stealth after next."
- *Ubiquitous technology*, such as the flow process microreactor and single-use bioreactor.
- *Asymmetric technology*, such as undetectable, shaped high explosives, or "pacificants."[35]
- *New baseline technology*, such as low observable, unmanned aerial vehicles.
- *Enabling industry*, such as additive manufacturing or design from "first principles."
- *Status technologies*, such as nuclear reactors, genetic laboratories, or microchip production.
- *Accretion technologies*, such as the cumulative effects of incremental improvements in microprocessors.

Each of these categories presents different degrees of possibility and diverse modes of impact on strategic latency.

Obviously, many technologies that seemed impossible not long ago have arrived. Cameras that can look into the past through wormholes in space–time, however, as envisioned by Clarke, are hypothetical because the wormhole in physics remains hypothetical. By analogy, however, we can see strategic implications associated with "staring sensors" that today record vast amounts of data over time and permit one to look back and reconstruct past actions and patterns.

Theoretical science could lead to applied technologies, such as the antimatter bomb, that would be consistent with physics laws, as we know them; but again, the main value in contemplating something theoretical in the actionable horizon of strategic latency is by analogy. Many such technologies are really extrapolations of capabilities already demonstrated, such as the "Tsar Bomba," the largest thermonuclear weapon ever tested.[36] Of more immediate interest are breakthrough technologies such as lasers that continue to advance toward an ever more emphatic dual-use status. Such advances encourage us to extrapolate technologies such as genetic manipulation to understand potential consequences. Often a new development, such as low-visibility technology for aircraft, is dominated by a successful "early adopter."

Eventually most technology spreads to others and may become ubiquitous. The value of a new technology may not be equal to all, so understanding asymmetric effects is important. Over time, most technologies become a new baseline technology so widely dispersed that it is not acquisition but failure to acquire that has the more important implications. Similarly, many developments become enabling technologies used by all as the foundation for other developments of more strategic interest. Some of these, such as nuclear reactors, bestow status on the beholders and that symbolism takes on strategic significance.

Most technological improvements might be called "better mousetrap technologies,"[37] a little better or cheaper or faster, but the world will probably not "beat a path to your door." These "accretion

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[33] See Stephen Baxter and Sir Arthur C. Clarke, *The Light of Other Days, A Novel* (New York: A Tor Book, 2000), based upon Sir Arthur C. Clarke, *Profiles of the Future: An Inquiry into the Limits of the Possible* (London: The Orion Publishing Group, 2000).

[34] http://public.web.cern./public/en/spotlight/SpotlightAandD-en.html, accessed March 29, 2012.

[35] See H. G. Wells, The Shape of Things to Come (1933), in which a global society of engineers enforces world peace by using a safe, nonlethal sleeping gas to subdue warring peoples outside the nonviolent, new world order they have established.

[36] http://nuclearweaponarchive.org/Russia/TsarBomba.html, accessed March 29, 2012.

[37] "Build a better mousetrap and the world will beat a path to your door" is attributed to Ralph Waldo Emerson.

technologies," however, can have strategic significance when small changes have magnified, cumulative effects, either positive or negative.

How an actor acquires a technology is also of interest to our understanding of strategic latency. The foundation is knowledge, which, when it is basic science, is generally widely available. Not all societies have developed intense, knowledge-based economies, but most could. Of course, some science and somewhat more technology involve intellectual property rights and national security secrecy. Patents, however, expire or are pirated, and secrets are often declassified for a number of reasons.[38]

Treaties or export controls restrict some technology transfer. Illegal diversion or covert activities are traditional nonproliferation concerns, but legal withdrawal from treaties following either legal or illegal activities to prepare for breakout is a scenario of considerable concern. In the case of the NPT, North Korea has withdrawn and Iran may. Sometimes the "haves" help the "have-nots." Sometimes the have-nots work together. The political, economic, and security dynamics of the acquisition of dual-use technology add complexity to any discussion of strategic latency, particularly when inequalities exist and norms are not agreed or internalized.

The impact of strategic latency may be global, regional, or local. The spread of missile technology enabling weapons of ever increasing range and heavier payloads illustrates this. The duration of strategic latency may show peaks, plateaus, and even oscillation of latent dual-use potential, which may result in situations of both acute and chronic concern.

Responding to Strategic Latency

A potential application of technology is actualized when an actor makes decisions and acts to exploit technology to which the actor has access. This may be good or bad for the actor and good or bad for others. Of particular interest here are dual-use technologies with strategic implications such as nuclear weapons. The challenge of strategic latency is that actions of concern may not be highly visible. They may come from many directions. Also, lead times may be so short that reaction times are inadequate, increasing the chance of surprise.

Typical strategies for responding to such emerging threats involve characterizing the risk, detecting action, assessing the meaning of events, and attempting to dissuade, prevent, deter, or in some cases preempt threatening actions. If avoidance cannot be achieved, then efforts are made to defend against, defeat, or recover from the action. Efforts to prevent or mitigate more threats in the future follow. In all of these cases, having sufficient information about the threat and time to react rationally and effectively is essential. Surprise undermines both the requirement for information and the requirement for response time.

Surprise arises for a number of reasons. We may not detect or identify the emerging threat. We may not evaluate the possibilities, probabilities, or consequences correctly. The dynamics of reactions and counterreactions may be confusing. Increased complexity can include "emergent behavior," when consequences are unexpected because their direction and magnitude seem uncharacteristic of the original

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[38] DOE declassification considerations include whether: (a) the information is so *widely known or readily apparent to knowledgeable observers* that its classification would cast doubt on the *credibility of the classification system*; (b) publication of the information would assist in the development of *countermeasures or otherwise jeopardize any U.S. weapon* or weapon system; (c) the information would hinder U.S. *nonproliferation efforts* by significantly assisting potential adversaries to develop or improve a nuclear weapon capability, produce nuclear weapons materials, or make other military use of nuclear energy; (d) publication of the information would have a detrimental effect on U.S. foreign relations; (e) publication of the information would benefit the public welfare, taking into account the importance of the information to public discussion and education and potential contribution to economic growth; and (f) publication of the information would benefit the operation of any Government program by reducing operating costs or improving public acceptance. See http://energy.gov/hss/office-health-safety-and-security, accessed March 29, 2012.

scenario. To avoid surprise or minimize its impact, we need to probe the concepts and reality of strategic latency.

Trends in Strategic Latency

We may better understand trends in latent dual-use technology with strategic implications if we examine in more detail some of the assumptions that are often associated with strategic latency. Perhaps the most fundamental hypothesis is that the enabling technology for simple and/or advanced weapons is increasingly widespread. What factors in technology might drive such a trend? Certainly, globalization and intense competition in technology markets feed off the synergy of multi-disciplinary science that is frequently also multi-mission. This phenomenon is called "technology push." "Technology pull" is generated by the need for diverse, modern warfare systems using advanced technologies such as electronics, sensors, and computations. Because more types of technology have become critical, more technology becomes significantly dual-use. These demands are met increasingly from multinational S&T markets manned by a global S&T talent base. Rather than being "silver bullets," much dual-use equipment and even some facilities are approaching commodity status. Agile manufacturing and miniaturization of equipment and facilities make more technology affordable as the increased productivity lowers infrastructure and manpower requirements.

This phenomenon is often accompanied by what in the digital age is referred to as "disintermediation" or "a more flat pyramid." Mid-level management is reduced as leaders come to control more employees directly, and empowered employees have greater access to more resources. Much general knowledge is spread by scientific advancement reported in the open scientific literature, a process intensified by increased exploitation of "open-source" science. Still, secrecy or patents protect much knowledge and know-how. Certain national security-related information is classified. Yet, leaks, theft, and the online publication of "cookbooks" not only make sensitive information available, but also highlight how to use it. Of course, not all of the technology of concern is cutting edge. "Hand-me-down" technologies move into the developing world, including regions experiencing violence and conflict, often to serve abandoned markets or to avoid regulatory burdens and political controversy. Research and production offshore may or may not be subject to oversight or responsible restraint.

A second hypothesis to be tested is that lead times from mere technology potential to a real weapon are shrinking. Little enabling knowledge remains secret in some fields. In others, favorable learning curves quickly yield lower cost, greater productivity, and higher quality. Just-in-time inventory strategies, possible because of networked computing, increase responsiveness in many sectors. Outsourcing reduces the lead time needed to build infrastructure, including civilian infrastructure that may be similar to that needed for the defense industry. Often these events occur overseas and exploit reduced oversight. Great wealth exists in troubled regions, and criminal organizations in some countries such as Afghanistan and Columbia may have strong ties to terrorist groups. Indeed, the weapons sought by terrorists or small states to meet their strategies may not have to be as sophisticated as those of powerful states.

A third hypothesis to be tested is that intelligence is difficult to obtain or unclear when dealing with strategic latency. Certainly, strategic latency and other forms of technological surprise are being carefully studied. Although many sources of latent, dual-use technology are "hidden in plain sight," such analysis has complications. Constraints exist on gathering industrial information, partly to protect privacy and partly based upon higher national security priorities. Even when warranted, analysis involves complex market structures with diverse participants, some of whom use mobile identities, false flags, front organizations, and frequent name changes. Even in legitimate activities, conflicting loyalties exist within organizations and among individuals. Outsourcing of steps in production can reduce the footprint of a production facility and its identifiable pattern, and just-in-time production can complicate analyzing activities. Legitimate dual-use activities can provide cover for latent WMD or other strategic capabilities and provide the foundation for development, legitimately or not, of nonstandard, novel, or parallel paths to weapons. Both rapid change and incremental steps can easily go unnoticed, and some activities implement polished concealment and deception plans. The transnational market in dual-use-potential technology sometimes involves innocents and unusual alliances among terrorists, rogues, and pariahs. All of this adds complexity to analysis that is often "stove-piped" and split between law enforcement and intelligence, each with different rules and objectives.

A fourth hypothesis worthy of examination is that vulnerabilities exist in modern societies that increase risk from leveraged threats. The growth of megacities and dependence on interconnected transportation and communications provides some redundancy and robustness, but it also introduces common modes of failure and exposure of large population concentrations. Modern economies are highly leveraged, both when they rise and when they fall. Economies, like societies, may also suffer when panic and demoralization are generated by acts of terror against people or national icons and symbols. Even in the case of military targets, attacking communications, logistic hubs, and command centers may be easier than attacking forces directly. The mere threat of such actions may drive the society threatened to expensive or otherwise undesirable countermeasures that result in self-inflicted harm.

If such vulnerabilities are serious, who would exploit them and who might be enablers? A fifth hypothesis then is competent, malicious actors seek highly destructive capabilities they do not now have and access is facilitated by legitimate actors and activities, as well as by some questionable players. That some terrorists with deadly motivation have an interest in acquiring destructive capabilities including WMD has been widely accepted since the 9/11 attacks. Prosecutions have been made of individuals who operate supply networks primarily for money. The presence in modern societies of ideological and religious extremists familiar with high technology and willing to support terrorist activities presents a challenge different from the more traditional extremists living in isolation in traditional societies, often suffering from the demographics of a high proportion of young, violence prone males. The rise of "home-grown" terrorists and mass murders suggests that multiple sources exist for dangerous people. Concern has been expressed that "copycat" behavior results in periods of escalating violence.

A sixth hypothesis goes to the heart of the concern about strategic latency: namely, that latency makes delayed or ineffective response likely. Clearly, awareness that diverse latent technologies can cause strategic surprise has grown, and many efforts are under way to understand the magnitude of the problem and to be more aware of technology activity of concern. Prediction, however, is an uncertain art, and governments are notorious at responding to threats ineffectively or too late. In fairness, any decision maker faces conflicting information and alternative explanations, the problem of false alarms, weak risk assessments, unattractive options for prevention or preemption, and competing interests. Common norms are difficult to enforce when faced with uncommon circumstances, but delay can devolve into increasing acceptance and "creeping normalcy" or even the "frog in the pot."[39]

A seventh hypothesis is perhaps key to the sixth, which is enforcement options are often unavailable or unattractive. Key sources of technology can be found in nations in turmoil or transition where corruption is extensive. Negative incentives are seldom popular, sanctions have an uneven history, and extraneous matters can easily distract the lengthy diplomacy required for international action. Even unilateral actions at home face privacy and property restraints.

If these hypotheses prove to be sound, then should we not expect technological surprise to arise from latent technology? If so, will it rise to the level of presenting strategic consequences? Will we face "tipping points," catalytic events, or transforming developments? And from whom? Nonstate, state-supported, and

[39] Notionally, a frog dropped in hot water jumps out immediately. A frog in water gradually heated will remain in the pot as its energy is sapped because no clear threshold causes it to jump.

substate entities? Failed or pariah states? Regional powers? Peer challengers? New blocs? For example, many efforts at export control, intellectual property protection, and production arrangements are seen by members of the Non-Aligned Movement as economic and protectionist activities, not nonproliferation activities. Disconnecting the economic and intellectual benefits of dual-use technology from the military and proliferation applications may require a level of close cooperation beyond that routinely achieved.

The Bright Side and The Dark Side of Strategic Latency

The advance and spread of S&T is overwhelmingly in the net interest of humanity. International cooperation and competition promote the advance and spread of technology locally as well as globally. Conditions for technological innovation or exploitation can be created in diverse cultures in economies of many sizes. Technology, like geography, offers different advantages or disadvantages to different users and therefore different values, leading to sequential, parallel, and divergent adoption patterns. Many theoretical, practical, and economical applications of a technology may not be obvious initially, and the accumulation of technology portfolios or capabilities to provide options and agility is a normal practice of industries and nations and creates latency—the potential for sudden and sometimes surprising exploitation. Latent potential for civilian or military use, however, may or may not be exploited and can be influenced. Technologies both prevent and create vulnerabilities. All technology is multiuse and carries some risk to a greater or lesser degree of being used in dangerous or destructive ways, legitimate or illegal.

Unexploited technology options create unclear and present dangers of strategic surprise. The same advances in science and spread of technology that accelerate global prosperity, freedom, and well-being create multiple technology options for weapons and military systems that may be exploited by some states and nonstate actors resulting in unwanted strategic surprise and challenge to others. Paths to latent capacity are not necessarily linear nor do they always follow well-worn paths. Rather new paths are possible, and new combinations of new varieties of technology are becoming more common. Strategic latency can be a condition, a strategy, or an explicit goal, and in each of these uses, it presents opportunities and risks.

The accumulation by nations, corporations, nonstate actors, and individuals of extensive, diverse, and complex technological portfolios provides options applicable to both benevolent and malevolent purposes. These factors place a premium on national security strategies more responsive to surprise, uncertainty, and instability.

Ghosts in the Machine: Defense against Strategic Latency

by Zachary S. Davis

Technological evolution is accelerating at breakneck speed. Even futurists struggle to keep pace with the unprecedented rate of scientific discoveries and technological innovation. As a result, the political, military, and economic consequences of new technology no longer plod along familiar pathways of development but are instead blazing new byways leading to unknown destinations. Tremendous technological power is increasingly in the hands of everyman, leaving established theories, policies, and institutions behind. Once distinct fields of inquiry—chemistry, biology, physics, computer science—are merging to produce new technologies that are latent with potential to help and hurt mankind, yet remain ungoverned by any legitimate authority. Will we be able to detect the emergence of strategically important technologies, some of which could pose grave dangers? If so, are we prepared to act?

Faster Than a Speeding Bullet

The great growling engine of change, technology.—Alvin Toffler

Visionaries such as Leonardo da Vinci, Jules Verne, and Walt Disney warned that technology innovation would rock our world. Today, even Moore's law, which boldly predicted that computing power would double every two years, has fallen behind the actual pace of technological progress. Futurists contemplate the emergence of "singularity," a milestone of technological advancement in which super-intelligence—made possible by the merging of humans and machines—will accelerate the accumulation of knowledge astronomically.[1] With or without singularity-fueled cyborgs, technology is reimagining the world in fundamental ways.

Countries no longer control research and development of cutting-edge technologies, the most consequential of which used to be "born secret" and remain controlled from cradle to grave. In fact, governments control a diminishing portion of the world's science and technology (S&T). Fifty-year-old nuclear weapon technology—the poster child for a high-leverage technology controlled by governments—is trafficked globally by gangs of proliferation entrepreneurs, such as A. Q. Khan. Potentially world-changing technologies in biology, lasers, nanotechnology, space, and computers are essentially ungoverned. Whatever the role of social media in facilitating the 2011 Arab Spring, few would argue that easy access to advanced communications technology is politically inconsequential.[2] John Q. Public increasingly has at his disposal capabilities with the power to challenge nation states.

Rapid global innovation in S&T is dispatching Marx and Keynes to the dustbin of history. Societies are no longer bound by classic models of industrial and economic growth. The new capitalists don't care about the old brick-and-mortar "means of production." Today, individuals create dynamic global networks to marshal the ideas and resources required to produce technologies latent with far-reaching security, economic, and political consequences. Money moves fast. Old, slow moving institutions built for hierarchical, ordered, step-by-step progress are being overtaken by quick-thinking, agile groups who can fund, research, test, prototype, and manufacture new products in the time it takes a government to issue a request for proposals. Advanced materials and manufacturing methods make possible a dizzying array of previously unthinkable products and opportunities. Instead of being the main incubator of technological

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[1] Ray Kurzweil, *The Singularity Is Near: When Humans Transcend Biology* (New York: Penguin Books, 2005). See also Kurzweil's website, http://www.sigularity.com.

[2] See for example Clay Shirky, "The Political Power of Social Media," *Foreign Affairs*, Jan/Feb 2011, and the exchange between Malcolm Gladwell and Shirky about the role of social media in political movements, "From Innovation to Revolution," *Foreign Affairs*, March/April 2011.

progress, governments are being pushed to the sidelines of major technological developments, some of which will have momentous consequences for national and international security.

The proponents and critics of globalization agree that, for better or worse, the defining characteristics of the nation-state are being radically altered by the free flow of information, people, and money.[3] However, while it is true that globalization has changed some aspects of sovereignty, national governments still represent the primary organizational unit within the international system. Reports of the decline of the nation state have been, as Mark Twain said of his own death, greatly exaggerated. National governments still exercise legitimate authority over territory, people, and the use of force. Nor are international organizations and substate actors poised to usurp power from the 195 countries recognized by the United Nations. Moreover, as Stephen Walt and John Mearsheimer have recently reiterated, nationalism still represents the most potent unifying force in world politics.[4]

Even if S&T have joined the growing list of things that governments no longer control, they have not undone the fundamental realities of the international system. Self-preservation inspires nations to address shifts in political, economic, and military power, including those brought about by S&T breakthroughs. Nations whose interests are directly affected by new technologies will take whatever actions are necessary to protect themselves, as countries around the world demonstrated as they dealt with the new reality of nuclear weapons after World War II. Not all nations will react in the same way, but familiar methods will be necessary to manage emerging threats. There is no alternative to the old-world tools of defense and diplomacy. And, as before, intelligence will be one of the keys to survival.

The S&T challenge for nations is twofold. First, states must recognize dangerous technological "black swans" before they can be harnessed to exploit national vulnerabilities. They include innovative uses of old technologies, such as terrorist's exploitation of cell phones and social media, as well as cutting-edge scientific developments that could be hurled such as a "bolt from the blue" to change, overnight, perceptions of national security. Examples include cyber hacking against economic, energy, or transportation infrastructure, and space technologies that undermine the effectiveness of space- or ground-based defense systems, such as electromagnetic pulse. Innovations in lasers and high-power microwaves could fall into this latter category.

The second reflects the opposite phenomenon, in which threats grow gradually, unnoticed until circumstances become dire and defenses ineffective. This phenomenon is the "frog in the pot" syndrome, with examples including climate change, negative demographic trends, or withering economic viability. For both challenges, nation states and their interests are the likely target and therefore will be motivated to respond. But in order to respond, they need to understand the scope and nature of the S&T challenges they face. They need to measure strategic latency in order to defend against it.

Measuring Weird Science

What's a cubit?—Bill Cosby as Noah

A central challenge in assessing S&T latency is the problem of measurement. Breakthroughs in fields such as medicine, robotics, high-performance computing, advanced materials, and nanotechnology are latent with potential military applications. Such latency has the potential to shift the global balance of power. But

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[3] Political scientists such as Robert Keohane initially praised the growing interdependence and multinational aspects of globalization. Economists touted the efficient use of labor, resources, and markets. However, labor unions and critics on the left such as Naomi Klein focused on the adverse effects of global free trade on workers, the environment, and corporate culture.

[4] John Mearsheimer, "Kissing Cousins: Nationalism and Realism," Yale Workshop on International Relations, May 5, 2011.

how do we measure power these days? If S&T latency is changing the international order, we need to account for it.

The high priest of power politics, Hans Morgenthau, defined the elements of national power in classic terms: geography, natural resources, industrial capacity, military preparedness, and population. He also added several often overlooked "soft power" factors such as national character, national morale, and the quality of government.[5] Governments employ crude measurements such as gross domestic product, debt ratios, and assessments of military capabilities to measure wealth and power and determine relative strength. Significant disparities of power among rivals can warn of dangers or opportunities. Although militarily latent technologies fall within a realist paradigm of power, we don't have a good measurement for these increasingly important factors in the global balance of power.

Measuring strategic latency requires a rough estimate of national scientific capacity, which is the base from which military options can be cultivated. The relatively new field of scientometrics tries to measure the overall progress of the sciences by tracking publications, patents, and other indicators of scientific achievement.[6] Areas of concentrated research activity suggest elevated levels of attention and, presumably, expectations for scientific achievement. This type of meta analysis, however, faces a number of difficulties when it comes to measuring technological latency.

As ever, necessity is the mother of invention. The field of psychophysiology—the study of the body's neurological responses to external stimuli—emerged in the 1940s when scientists realized they needed data on which to develop sound scientific theories.[7] They needed new tools to collect, measure, and analyze the output from their experiments. Scientists devised new instruments to measure neurological behaviors such as heart rate, sweating, blinking, twitching, and stomach gurgling. The result was a new generation of electrodes that made it possible to measure a range of neurological phenomenon.[8] Armed with the data they needed, they were able to test new theories through experimentation and advance their field.

One unintended result of this research was the invention of the lie detector. However, in a series of studies conducted for the U.S. government, psychophysiologists concluded that it was scientifically invalid to draw conclusions about an individual's underlying intentions from measurements of their physical reactions to probing questions. The data simply does not explain *why* a person responds to provocative or insinuating questions with an accelerated heart rate, sweating, or other measurable physical reactions. The signs of discomfort measured by the machine could result from a number of possible causes, with intentional lying being just one possibility. The intent behind the apparent discomfort remains opaque.[9]

A similar problem exists with measuring latency. Scientometric analysis that finds spikes of activity in certain scientific disciplines can not explain the intent behind the development of latent S&T capabilities, much less their future applications. Moreover, even if it were possible to map the general direction of scientific inquiry, important discoveries often result from accidents, as in the case of penicillin and X-rays,

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5 Hans Morgenthau with Kenneth W. Thompson, *Politics Among Nations*, 5th edition (New York: Knopf, 1973).

6 Several academic journals are dedicated to the study of scientometrics, sometimes characterized as the science of science. Scientometrics uses quantitative methods to analyze scientific literature, databases, patents, publications, and other information. Examples include *The Journal of Scientometric Research, Scientometrics, and Collnet Journal of Scientometrics and Information Management.*

7 Frances Gabbay and Robert Stern, "A Quiet Voice: Roland Clark Davis and the Emergence of Psychophysiology," *Psychophysiology* **49**(4), 443–453.

8 Robert Stern, William Ray, and Christopher Davis, *Psychophysiological Recording*, First Edition (New York: Oxford University Press, 1980).

9 Gabbay and Stern, "A Quiet Voice: Roland Clark Davis. . . .

neither of which could have been predicted as a linear consequence of general trends in scientific research at the time. Scientometric methods cannot account for the unexpected black swans or the frog happily swimming in the warming pot. As with the polygraph, the data cannot account for key variables such as human nature, chaos, and politics.

Prediction is as difficult as it is irresistible.[10] However, technology foresight methods can be useful as a systematic way to bound the realm of the possible and thereby enable analysts to focus on higher probability scenarios.[11] In addition to purely scientific trends, technology foresight methods take into account the myriad social, political, and economic factors that shape the context in which new technologies are created and nurtured. Globalization requires us to pay more attention to the subnational entities that actually develop and control new technologies. Foresight studies such as those conducted by the RAND Corporation correlate scientific trends with national policies and institutional capacities to assess which technologies are most likely to develop in a particular environment, their likely applications, and possible obstacles such as the availability of funding and expertise. This type of analysis calls attention to latent applications as the ingredients for strategically significant capabilities come together. Once latent potential has been identified, additional information and analysis are needed to determine if a group or country is contemplating military applications.

Recognizing Strategic Latency

It is neither good nor bad, but thinking makes it so. . . .—Shakespeare, Hamlet

U.S. Supreme Court Justice Potter Stewart's observation about pornography—"I know it when I see it"—applies to latency. Technology is value neutral until someone uses it. How, then, do we recognize and measure strategic latency, the potential to exploit S&T for good or evil? Armed with foresight knowledge about latent capabilities, nation states need to know if competitors or adversaries are acquiring and developing particular technologies to exploit their military potential. Increasingly, states may seek to become as latent as possible without crossing any technical or political redlines that would trigger unwanted reactions, as several countries have done with respect to nuclear capabilities. By hiding behind legitimate S&T that can be readily transformed into military power, the possessor can hedge against future threats without setting off alarm bells.

To understand the true intent behind latent capabilities, analysts need information about the leaders who direct the relevant policies and resources governing the direction and priorities of S&T programs. Clues about strategic intentions may lie in the organizations and decision-making structures charged with formulating and implementing national or subnational policies. It is one thing to have a powerful laser, quite another to point it at a satellite. Although the technologists who create latent capabilities may not know the ultimate purpose for which their services are employed, they may understand the latent potential of their research and development (R&D), and they may have interacted with military leaders regarding the possibilities for weaponization. Scientists are famously alert to the nefarious application of their labors. The Manhattan Project, for example, was abuzz with discussion about the political and moral implications of atomic weapons. Genetics is another field where ethical issues are hotly debated. Evidence of malevolent intent comes from the people involved.

Existing intelligence methods, guided by ongoing technical analyses to track S&T trends, can reveal an adversary's intentions to acquire and use emerging S&T weapons. Where S&T analysis identifies growing latency in particular areas of R&D, human intelligence is the key to providing adequate warning of a "bolt

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[10] Richard Danzig, "Driving in the Dark: Ten Propositions About Prediction and National Security," Center for a New American Security, October 2011.

[11] Richard Silberglitt, "Technology Foresight, Social Equity, and International Stability," RAND Corporation, September 2011.

from the blue" technological surprise. Communications among insiders conspiring to weaponize emerging technology would trigger defensive actions. Warnings about gradual, "frog-in-the-pot" shifts in global power rely more heavily on long-range forecasting and less on clear evidence of calculated intent to do harm. In both cases, sufficient information should be available to warn decision makers about S&T latency.

Of course, how countries respond to such warnings will vary. Evidence of gradually accumulating foreign S&T capabilities in the hands of competitors will be viewed differently than timely information about plots to weaponize specific technologies. Evidence that actual high-tech weapons are being developed or deployed should be viewed as a threat to national security requiring appropriate action. Long-term threats, such as global warming, adverse demographic trends, loss of economic competitiveness, or even unrealized futuristic weapon concepts, are politically easier to kick down the road. Addressing gradually encroaching threats may require politically demanding remedies that challenge national policies toward education, energy, or perhaps the role of women. Even if the frog wants to get out of the pot, it won't be easy, although the alternative is even worse. Ideally, leaders will adopt policies to address both out-of-the-blue and gradual latency. Failure to act is more likely to result from a lack of will than a lack of knowledge.

Warfare and Latency

Our inventions mirror our secret wishes.—Lawrence Durrell

New weapons will always find new uses. States and nonstate actors may be tempted to exploit latent S&T capabilities to achieve a variety of political, economic, and military ends. Rather than use innovative new weaponry to support old-fashioned battlefield clashes against traditional adversaries, aggressors may find more utility in covert, discreet attacks on specific economic or political targets. In the future, subtle, hard-to-detect strikes intended to degrade confidence and productivity may be more attractive than wars to defeat armies and claim territory. Technological latency could give new impetus to the use of economic warfare as an expression of "politics by other means."

Recent reports of cyber attacks on equipment and infrastructure may portend a new chapter in the history of warfare in which hostilities are not declared and battles remain unacknowledged.[12] Victory and defeat may be measured in terms of suspicious crop failures, unreliable commercial services, or malfunctioning goods that result in shifting consumer loyalties. Using innovative S&T tools to undermine confidence in foreign companies and products may be easier, less risky, and more desirable than using advanced weapons to settle political disputes through armed conflict. Covert use of advanced S&T "weapons" to undermine competitors may become common among so-called "frenemies" and perhaps even among allies.

Emerging S&T weapons that open new horizons for global competition will also augment the world's fighting capabilities. Advanced communications, robotics, lasers, new materials, and space assets will improve the effectiveness and lethality of conventional land, sea, and air forces. In addition to moving faster, deeper, and farther and being harder to detect, advanced weapon systems will benefit from improvements in intelligence, surveillance, and reconnaissance capabilities that will continue the trend toward increased precision and timeliness. Unmanned, stealthy, long-dwell, stand-off platforms will be able to strike targets anywhere, anytime. Traditional notions of sovereignty will suffer.

Advanced S&T will challenge the rules of warfare, as new weapons have throughout history. New weapon concepts may offer tactical advantages to those willing to circumvent existing norms and treaties banning the use of chemical, biological, or space-based weapons. Designer drugs formulated to target specific

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[12] Richard Clarke, *Cyber War: The Next Threat to National Security and What to Do About It* (New York: Harper Collins, 2010).

genetic characteristics of particular ethnic groups might be seen as useful for subduing political unrest.[13] New generations of incapacitating agents might be useful for counterterrorism and counterinsurgency efforts, as Russia demonstrated in its use of an analgesic gas against Chechen terrorists who took hostages in a Moscow theater in 2002.[14]

On the battlefield, temporary spells of blindness, sickness, or debilitation could enable advancing armies to disarm their opponents before a shot is fired. Covert use of such techniques may be hard to detect. Moreover, use of debilitating technologies against targets within one's own territory would blur the already fuzzy distinctions between war, counterterrorism, and law enforcement. Advancements in nonlethal weapons could make limited war and humanitarian intervention more attractive. New norms of nonuse may be harder to promote. Only the most stubborn optimist would contend that the benefits of emerging S&T will not also be applied to the military arts.

New weapons derived from strategic latency will not necessarily constitute weapons of mass destruction (WMD). [15] In fact, damage limitation and nonlethality may be among the most appealing characteristics of the new weapons, and they may make the new weapons more usable. Throughout the ages, new weapons have raised moral questions. Norms of behavior eventually evolved against indiscriminant mass killings, especially of noncombatants. Winston Churchill in 1955 described the new moral hazards created by the advent of nuclear, chemical, and biological weapons when he observed that "safety will be the sturdy child of terror, and survival the twin brother of annihilation."

Credible threats to use the new weapons could make their actual use less thinkable. Use of chemical and biological weapons, and even small nuclear weapons, would cross a moral threshold. Treaties such as the Nuclear Non-Proliferation Treaty, the Chemical Weapons Convention, and the Biological Weapons Convention enshrined the new norms of international behavior. However, future weapons that kill with surgical precision, spare the lives of soldiers and citizens alike, or selectively target commercial assets may not evoke the same level of moral trepidation as modern WMD and may not inspire similar conventions of nonuse. If S&T innovations produce advantageous military capabilities, they will be used.

Defense Against Strategic Latency: Implications for Policy

If you do not expect the unexpected, you will not find it, for it is not to be reached by search or trail.—Heraclitus

Although global strategic latency poses difficult challenges, they are part and parcel of the broader trends that are reshaping international society. For countries, companies, organizations, and individuals planning to compete in the new world order, there is no escaping these challenges. And despite the opportunities that technology provides for devising innovative solutions to those challenges, the basic tools available to cope with national security remain unchanged. Because nothing about latency changes the fundamental realities of war and politics, we must incorporate strategic latency into our current policies of defense and diplomacy. An effective strategy to cope with latency should include the four components discussed below.

[13] J.M. Appel, "Is All Fair in Biological Warfare? The Controversy Over Genetically Engineered Biological Weapons," *Journal of Medical Ethics* **35**(7), 429–432.

[14] "The Moscow Theatre Hostage Crisis: Incapacitants and Chemical Warfare," James Martin Center for Nonproliferation Studies, http://cns.miis.edu/stories/02110b.htm, accessed January 16, 2012; and David Hoffman, "Genetic Weapons, You Say?" *Foreign Policy*, March 27, 2012, http://hoffman.foreignpolicy.com/posts/2012/03/27/genetic_weapons_you_say.

[15] Seth Carus, "Defining Weapons of Mass Destruction," National Defense University, WMD Center, Occasional Paper no. 4, January 2006.

1. Detect emerging S&T threats:

- Intelligence remains at the heart of defense strategy, and the intelligence community (IC) must stay abreast of global S&T trends. The IC will have to expand beyond its traditional methods of collection and analysis to include interaction with the scientific community as well as those in the private sector who fund and market new technologies. The national laboratories are a natural interface between the IC and the scientific world.
- Counterintelligence is an essential component of a strategy to cope with latency. Not only can it help reveal the priorities of those seeking to acquire emerging technologies through illicit methods, but it also creates opportunities for offensive actions against national espionage or sabotage efforts. Counterintelligence will be specially relevant in securing global supply chains against efforts to subvert reliability or introduce counterfeit goods. In a world in which legal norms, academic standards, business practices, and ethical considerations are in flux, counterintelligence will play a bigger role in revealing and combating hidden motives.
- Public health monitoring provides timely information about global medical conditions. Efforts to improve international detection, monitoring, and analysis of disease also serve as early warning of nefarious uses of biotechnology.
- International science engagement will be increasingly valuable as a means of understanding global S&T developments. Person-to-person contacts among researchers worldwide can serve as early warning indicators of emerging strategic latency and intent to weaponize. A network of scientists alert to the signs of S&T exploitation for military applications could call attention to such activity without infringing on the freedom or integrity of fellow researchers.

2. Defend against latency:

- Threats to retaliate against aggressors by means of one's own choosing are a major element of an effective counter-latency defense strategy. It may not be possible to deter the acquisition of latent military power, but deterrence against its use remains valid. Adversaries must know that major attacks using emerging S&T (such as cyber, electromagnetic pulse, biological agents) will be considered acts of war and will result in unacceptable damage to the perpetrator.
- Identifying the source of an attack can be difficult and will require advances in attribution and forensics technologies.
- Devising credible and justifiable retaliatory actions in response to a variety of new and unconventional threats is a challenge. Innovative thinking is needed to establish proportionality and equivalence among new technologies as well as declaratory policies to convey deterrence postures. For example, how would a nation calibrate an appropriate response to a verified attack on its agriculture or a cyber attack on its financial sector? Effective deterrence against S&T threats may not necessarily be limited to tit-for-tat responses with equivalent technologies (such as cyber for cyber, bio for bio) against official government-owned targets. In most cases, conventional military action may be the most credible option for retaliation. Deterrence against nonstate actors remains problematic.
- Preparedness against attack is a central pillar of defense and deterrence. Demonstrating to our adversaries that our military can fight through temporarily disabling environments and that our society can rebound from unconventional attacks sends a powerful signal to anyone contemplating using innovations in S&T against the U.S. civil preparedness against S&T latency should include robust public health measures (such as monitoring, medical emergency response capabilities,

vaccines, exercises),[16] public-private partnerships, emergency energy and food supplies, and other measures to help communities withstand and recover from natural as well as man-made disasters. Cold-war civil defense provides a model.

3. Defeat new weapons:

- Aggressive research on the potential military applications of emerging technologies as well as R&D on countermeasures are essential to defend against a "bolt from the blue" technological surprise. Innovative military applications of new technologies, such as those spearheaded by the Defense Advanced Research Projects Agency, should be considered, including unconventional warfare options. However, as defense budgets shrink, R&D for exotic weapons is likely to decline.
- Personnel, communications, and supplies on the battlefield should be secured against the most likely disruptive and contaminating agents. Current efforts to protect the military and the homeland against chemical, biological, radiological, and nuclear weapons provide a good template. Ongoing efforts to develop and deploy new vaccines benefit military and civilian assets. Not all forces will need protection against all possible threats.
- Military countermeasures may provide a last line of defense, once it has been confirmed that potential adversaries have sufficient levels of intent and capability to field exotic new weapons. We should develop conventional strike options against adversaries using advanced S&T weapons. Counterproliferation policy and planning provides a good start for counter S&T operations.

4. Compete to maintain S&T leadership:

- The best defense against foreign S&T latency is to lead the world in advanced S&T. Staying ahead of the knowledge curve helps prevent surprises and lays the groundwork for developing defensive and offensive applications. The U.S. lead is slipping as other countries, including the so-called BRICs (Brazil, Russia, India, China), build their economies and close the gap with the leading industrialized nations. Several are investing national resources to boost their S&T capabilities.[17] Such investments are made possible by strong economies and may be harder to justify in tough economic times. However, private enterprise and the free market are not sufficient shepherds of national security interests. Nation states are responsible for safeguarding S&T competitiveness, among other national interests.
- Education is the key to S&T competitiveness. A steady decline in science and engineering expertise constitutes a national weakness that competitors will exploit. Dependency on foreign graduate students may help fill gaps in basic science capacity, but it will not be sufficient to address S&T requirements in the most sensitive national security applications. Technical expertise is needed in the bureaucracy.

Vexing challenges will accompany the great comforts brought about by rapid technological progress. The private sector will aggressively pursue technologies that offer a high rate of return on investment, regardless of their latent security implications. The politics of latency, however, make it unlikely that the U.S. (or any other country) will be proactive in preparing for imagined dangers that sound more like science fiction than military threats.

The small cadre of S&T specialists focused on the national security implications of emerging technology will be hard pressed to warn of an imminent technological Pearl Harbor or predict unprecedented

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[16] "The Bipartisan WMD Terrorism Research Center's Bio-Response Report Card: 21st Century Biological Threats," (Washington D.C:, WMD Center, October 2011).

[17] *S&T Strategies of Six Countries: Implications for the United States* (Washington D.C.: National Academies Press, 2010).

applications of exotic new discoveries. Even if they do, without a smoking gun pointing to a hostile enemy, such warnings are likely to be lost among competing priorities. Even the best predictive models will not pinpoint the nature and timing of emerging technological threats. Moreover, limited resources make it tempting to defer the precautionary actions needed to address latent threats, especially long-term investments in education and research that appear to offer few immediate material or political benefits. Nevertheless, it is the responsibility of nation states to identify and defend against the negative aspects of emerging S&T. Governments will be held accountable for protecting their citizens.

Nuclear Latency, Nonproliferation, and Disarmament

by Joseph F. Pilat

Latency, which poses an over-the-horizon, technological threat that could result in strategic surprise, is not fully encompassed and explored in the policy debates over nuclear weapon proliferation. Nor is it addressed in the treaties, institutions, and norms designed to address these threats through nuclear nonproliferation, arms control, and disarmament. Iran's nuclear program has raised the issue at one end of the continuum; revitalized interest in disarmament lies at the other. Is nuclear latency unique? Is latency a condition for nuclear-weapon states and for many nonnuclear-weapon states? Can it be a strategy for proliferant states? Can it be a viable nonproliferation strategy? To what extent will latency exist in a nuclear–free world? Will latency be a positive or negative force for future efforts to control or eliminate nuclear weapons? This paper explores these issues in the context of longstanding aspirations to promote nuclear nonproliferation and disarmament.

Nuclear latency is the inevitable consequence of the pursuit of nuclear technology, whatever the purpose or intent. It shares some latency issues with other dual-use technologies, but it has unique elements as well. Unlike technologies that could result in strategic surprise, or pose a serious strategic military or other security challenge only when linked to other technologies or to new operational concepts, nuclear technology was seen at the outset to be in itself revolutionary. Nuclear technology was forged during wartime, but it can also be used for peaceful purposes. The threat of strategic surprise emanating from dedicated weapon programs or the misuse of civil programs has been ever present in policy makers' and academics' minds. At the dawn of the nuclear age, decision makers believed that a small arsenal, even a single weapon, could change the strategic equation. The threat did not depend only on delivery capabilities. The threat was intrinsic to the weapon. Only by eliminating nuclear weapons or by deterring their use could the danger be reduced. The danger involving peaceful uses, which could be diverted to military applications, also placed a premium on creating effective international controls.

The Acheson-Lilienthal Report, the Baruch Plan, and the Concerns about Latency

Concerns about latency in the form of the possible misuse of civilian nuclear power programs for military purposes were much on the minds of the authors of the Acheson-Lilienthal Report and the subsequent Baruch Plan that was based on it.[1] The report "recognized that the industry required and the technology developed for the realization of atomic weapons are the same industry and the same technology which play so essential a part in man's almost universal striving to improve his standard of living and his control of nature."[2] More specifically, it declared: "The development of atomic energy for peaceful purposes and the development of atomic energy for bombs are in much of their course interchangeable and interdependent."[3]

While recognizing the inherent dual-use nature of the nuclear fuel cycle, the Acheson-Lilienthal report drew distinctions between "dangerous" and "safe" activities. In its reasoning, a nuclear activity is dangerous if it offers a solution to any of three major problems of proliferation: obtaining raw material, producing fissionable materials, and fabricating a weapon. Dangerous activities were identified as uranium

[1] See *A Report on the International Control of Atomic Energy, Prepared for the Secretary of State's Committee on Atomic Energy* (Washington, D.C.: U.S. Government Printing Office, March 1946), and "Statement of United States Policy," presented to the United Nations Atomic Energy Commission by U.S. Representative Bernard Baruch, June 14, 1946, http://www.atomicarchive.com/Docs/Deterrence/BaruchPlan.shtml.

[2] *A Report on the International Control of Atomic Energy,* 2.

[3] Ibid., 4.

and thorium mining, operation of plutonium production reactors and reprocessing facilities, and weaponization. Safe activities were those involving relatively small amounts of fissile material, fissile material production facilities of low capacity, and certain types of power reactors. The report proposed that "dangerous" nuclear activities be reserved for an international "Atomic Development Authority" (ADA) that would own and license the use of all fissile material. "Safe" activities would be allowed to be carried out by individual nations.

The line between dangerous and safe activities was not set in stone and could be affected by technological action. This issue was raised in the report's discussion of "denaturing." According to the report:

. . . U 235 and plutonium can be denatured; such denatured materials do not readily lend themselves to the making of atomic explosives, but they can still be used with no essential loss of effectiveness for the peaceful applications of atomic energy. They can be used in reactors for the generation of power or in reactors useful in research and in the production of radioactive tracers. It is important to understand the sense in which denaturing renders material safer. In the first place, it will make the material unusable by any methods we now know for effective atomic explosives unless steps are taken to remove the denaturants. In the second place, the development of more ingenious methods in the field of atomic explosives which make this material effectively useable is not only dubious, but is certainly not possible without a very major scientific and technical effort.[4]

The report recognized that denaturing, which transforms fissile materials so they cannot be used in nuclear weapons, could be reversed. But the authors held that "doing so calls for rather complex installations which, though not of the scale of those at Oak Ridge or Hanford, nevertheless will require a large effort and, above all, scientific and engineering skill of an appreciable order for their development."[5]

The authors were overly hopeful of denaturing, even though they did not give full support to the dream of dividing the civil from the military atom. Inspections were also soundly dismissed. The report unanimously concluded that "there is no prospect of security . . . [for a system] which relies on inspection and similar police-like methods."[6]

Given these limits, the report held that in order to best ensure against technological surprise and breakout, the proposed ADA would have to be at the cutting edge of nuclear science and technology:

…one of the important things that the Authority will have to do is research in atomic explosives. We are by no means sure that important new discoveries in this field do not lie ahead. Possibly the study of atomic explosives may yield byproducts useful in peaceful activities. But this will not be the main purpose of the Authority's research. Only by preserving its position as the best informed agency will the Authority be able to tell where the line between the intrinsically dangerous and the non-dangerous should be drawn. If it turns out at some time in the future, as a result of new discoveries, that other materials lend themselves to dangerous atomic developments, it is important that the Authority should be the first to know. At that time measures would have to be taken to extend the boundaries of safeguards.[7]

The authors recognized that even this would not be sufficient in a world without nuclear weapons. The report understood that there was a need *inter alia* "to provide security while allowing states to maintain a relatively secure position if there are problems; to be able to deal with unanticipated new threats; to

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[4] Ibid., 26–27.

[5] Ibid., 27.

[6] Ibid., 4.

[7] Ibid., 36.

provide unambiguous and reliable danger signals of noncompliance; [and] to deal with the problem of enforcement."[8] The report stated:

In strengthening security, one of the primary considerations will relate to the geographical location of the operations of the Authority and its property. For it can never be forgotten that it is a primary purpose of the Atomic Development Authority to guard against the danger that our hopes for peace may fail, and that adventures of aggression may again be attempted. It will probably be necessary to write into the charter itself a systematic plan governing the location of the operations and property of the Authority so that a strategic balance may be maintained among nations. In this way, protection will be afforded against such eventualities as the complete or partial collapse of the United Nations or the Atomic Development Authority, protection will be afforded against the eventuality of sudden seizure by any one nation of the stockpiles, reduction, refining, and separation plants, and reactors of all types belonging to the Authority.[9]

The authors of the report argued that the U.S., with Hanford, Oak Ridge, and Los Alamos, may evoke fear in other states that can only be mitigated

. . . *as the Atomic Development Authority locates similar dangerous operations within their borders. Once such operations and facilities have been established by the Atomic Development Authority and are being operated by that agency within other nations as well as within our own, a balance will have been established. It is not thought that the Atomic Development Authority could protect its plants by military force from the overwhelming power of the nation in which they are situated. Some United Nations military guard may be desirable. But at most, it could be little more than a token. The real protection will lie in the fact that if any nation seizes the plants or the stockpiles that are situated in its territory, other nations will have similar facilities and materials situated within their own borders so that the act of seizure need not place them at a disadvantage.*[10]

More would be needed, in their view:

The design of primary production plants should make them as little dangerous as possible. The stockpiles of materials suitable for the production of bombs should be kept as small as possible consistent with sensible economics and engineering. So far as practicable, stocks should be denatured or kept in low concentrations unsuitable for the production of bombs. In other words, the design and operating procedures should definitely prevent the accumulation of substantial amounts of material quickly convertible into important quantities of explosives.[11]

In effect, the response to noncompliance and the threat of breakout would be the prospect that other advanced states could arm or rearm in reaction. The distribution of latent capability across the globe would enable this response. Although latency would provide a measure of security for those states that feared the U.S. rearming, the very idea would be highly unstable as states rushed to arm at the first sign of a crisis. Nonetheless, the authors of the report regarded it as a deterrent.

The Acheson-Lilienthal report was not a proposal for the control of atomic energy per se. However, it served as the basis for the Baruch Plan, which was presented to the United Nations Atomic Energy Commission (UNAEC) on June 14, 1946. The Baruch Plan recognized the latency issue laid out in the earlier report; however, it did not provide the same solution for addressing latency-driven breakout scenarios. As noted, Acheson-Lilienthal proposed distributing facilities and capability so that a state's efforts to break out could be countered by all other states. Baruch, in contrast, called for "condign punishment" of violators. He stated:

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[8] Ibid., 9–10.

[9] Ibid., 47.

[10] Ibid.

[11] Ibid., 47–48

We must provide the mechanism to assure that atomic energy is used for peaceful purposes and preclude its use in war. To that end, we must provide immediate, swift, and sure punishment of those who violate the agreements that are reached by the nations. Penalization is essential if peace is to be more than a feverish interlude between wars. And, too, the United Nations can prescribe individual responsibility and punishment on the principles applied at Nuremberg by the Union of Soviet Socialist Republics, the United Kingdom, France and the United States—a formula certain to benefit the world's future.[12]

The heart of Baruch's message was the need to deal with any violations effectively, including the elimination of the Security Council veto for the five permanent members. This appears to have reflected concerns expressed in the original report. According to Baruch:

It would be a deception, to which I am unwilling to lend myself, were I not to say to you and to our peoples that the matter of punishment lies at the very heart of our present security system. It might as well be admitted, here and now, that the subject goes straight to the veto power contained in the Charter of the United Nations so far as it relates to the field of atomic energy. The Charter permits penalization only by concurrence of each of the five great powers—the Union of Soviet Socialist Republics, the United Kingdom, China, France, and the United States.

I want to make very plain that I am concerned here with the veto power only as it affects this particular problem. There must be no veto to protect those who violate their solemn agreements not to develop or use atomic energy for destructive purposes.[13]

Amid emerging Cold War rivalries—as well as the Soviet Union's bomb program and its suspicion of U.S. motives—the proposal languished in the UNAEC. In the Third Report of the Atomic Energy Commission to the Security Council, of May 17, 1948, the commission reported that it cannot prepare a treaty draft.

After Baruch, the idea of an international control regime to reduce the dangers of nuclear arms and energy was no longer a focus of policy makers. Disarmament was largely off the table during the Cold War, and the nuclear threat was dealt with through deterrence and halting, modest arms control efforts. President Eisenhower's Atoms for Peace speech laid the foundation for a far less ambitious international nuclear nonproliferation regime. It was in this context that latency was a proliferation issue in the ensuing decades. The issue was based on the fear that the growth of nuclear energy programs for peaceful purposes would create latent weapon capabilities. When interest in disarmament was revived in recent years, latency in this arena was linked to, and shared the spotlight with, proliferation latency.

The Non-Proliferation Treaty, Nuclear Power Growth, and a Disarmament Revival: Renewed Concerns about Latency

During the Cold War, the fears about the proliferation potential of civilian nuclear power programs waxed and waned, depending in part on the perceived prospects for nuclear power, and were especially intense in the 1970s. Despite the Treaty on the Non-Proliferation of Nuclear Weapons (NPT), which entered into force in 1970, the Indian test of a so-called "peaceful nuclear explosion" and the prospect of dramatic, even exponential, nuclear power growth raised fears of uncontrolled proliferation. The 1977 report of the Ford-MITRE Nuclear Energy Policy Subgroup, *Nuclear Power: Issues and Choices*, reflected the concerns of the times, arguing on the basis of the long-standing recognition of the link between nuclear power and weapon capability, that the "growth and diffusion of nuclear power. . .inevitably enhance the potential for the proliferation of nuclear weapons. "[14]

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[12] Baruch, "Statement of United States Policy. . . ."

[13] Ibid.

[14] *Nuclear Power: Issues and Choices*, Report of the Nuclear Energy Policy Subgroup, sponsored by the Ford Foundation, administered by the MITRE Corporation (Cambridge, MA: Ballinger Publishing Company, 1977), 22.

On this basis, the report stated:

The consequence of nuclear power that dominates all others is the attendant increase in the number of countries that will have access to the materials and technology for nuclear weapons. At the beginning of 1976, fifteen non-nuclear weapon countries had operational power reactors, each generating as a by-product enough plutonium for a few to a score or more bombs annually. When reactors now on order or under construction are completed in the mid-1980s, the number of countries will double and amounts of plutonium will increase rapidly. In addition to the danger of peacetime "proliferation" of announced and demonstrated weapon capabilities, there will be a spread of potential capabilities that could be activated in a crisis.[15]

In the view of the report's authors, "If widespread proliferation actually occurs, it will prove an extremely serious danger to U.S. security and to world peace and stability in general."[16] However, unlike many at the time who argued that every reactor is a "bomb factory" and the "world will be awash in plutonium," the authors did not argue this possible future was inevitable, stating, "Despite this somber appraisal of the technical situation, nuclear weapons are not an inevitable consequence simply because the technical capability has been achieved, as West Germany, Japan, Canada, and Sweden demonstrate."[17]

The authors thought the risks of nuclear power could be managed. However, they saw a clear and present danger and recognized that the emerging nonproliferation regime was challenged:

At the present moment, the nonproliferation venture is under test. The ambiguous Indian "peaceful" explosion of 1974 was a reminder of the nuclear weapons potential of a growing number of states. At international tension points, rival insecure or ambitious states confront each other. If one or more states overtly "go nuclear" in the near future, there is a risk of a chain reaction of nuclear commitments by imitators or rivals. At this crucial time, nuclear power is spreading and bringing with it growing basic nuclear capabilities. In the United States and in other countries with nuclear power programs, technical decisions are impending whether to proceed with plutonium reprocessing and recycle and with breeder development, which could constitute a watershed for proliferation.

The current active spread of nuclear power industries thus could be attended by widespread availability of separated plutonium or highly enriched uranium usable in weapons and the fuel cycle facilities for producing, separating, and handling them. Many nations would be only a step or two from a nuclear weapons competence if they decided to go that route. The nonproliferation regime which currently prevails, and indeed international stability, could be subjected to a new and perhaps intolerable strain.[18]

By retarding expected nuclear growth, the Three Mile Island and Chernobyl events mitigated concerns that latent capability would spread with the exponential growth of nuclear power. This effect lasted for two decades, but it did not end the concerns that centered on the weapon latency in civil nuclear power programs.

During the Cold War, with disarmament at best a distant objective or dream, nonproliferation and arms control defined what was possible in reducing nuclear dangers. In the aftermath of the Cold War, the Gulf War, and the decisions of South Africa, Belarus, Ukraine, Kazakhstan, and Libya to give up nuclear arms or development programs, the changing international security environment has created at least the hope of rolling back proliferant nuclear arsenals and nuclear disarmament. However, during this period, proliferation has continued and has appeared on the verge of a tipping point, with concerns about latent capabilities derived from nuclear power programs a critical factor in the equation.

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15 Ibid., 271.

16 Ibid., 22.

17 Ibid.

18 Ibid., 272–273.

In the first decade of this century, noncompliance cases, especially Iran, along with the pre-Fukushima hope for a nuclear renaissance, revived the fears and the debate of the 1970s. At the same time, building on arms control successes in the 1980s and 1990s, governments and nongovernmental organizations around the world have shown a growing interest in, and hopes for, nuclear disarmament. The visions of the so-called "Four Statesmen"—George Schultz, Bill Perry, Henry Kissinger, and Sam Nunn—and the Obama Administration are changing the debate, even though their specific proposals can be fully discussed without raising the critical issues that have dominated the nuclear disarmament debate since the dawn of the nuclear age.

Uncertainties and instabilities surround both proliferation and disarmament, and the emerging global environment will undoubtedly affect thinking and behavior related to the control and safeguarding of nuclear-weapons technology. The new environment raises issues of latency, which, as noted, have received little attention. More importantly, there have been no direct efforts to address latency in any bilateral or multilateral nonproliferation, arms control and disarmament agreements since the Acheson-Lilienthal report.[19]

The NPT did not proscribe latency; in fact, it fostered the role of the treaty in creating latent capability through the nuclear fuel cycle. Moreover, nothing in the treaty limits research and development (R&D) or the pursuit of knowledge and experience relevant to nuclear weapons, which is evident in the language and negotiating histories of key articles of the treaty. The treaty articles in question are Article II, in which nonnuclear-weapon states (NNWS) undertake "not to manufacture or otherwise acquire nuclear weapons or other nuclear explosive devices"; Article III, which provides for safeguards administered by the International Atomic Energy Agency (IAEA); and Article IV, which provides that nothing in the treaty is to be interpreted as affecting the right of all parties "to develop research, production and use of nuclear energy for peaceful purposes . . . in conformity with Articles I and II of this Treaty."

In the course of treaty negotiations, U.S. representatives were asked what would constitute the "manufacture" of a nuclear weapon or other nuclear explosive device under Article II of the draft treaty. In testimony on the NPT before the Senate Foreign Relations Committee on July 10, 1968, then-Arms Control and Disarmament Agency Director William Foster suggested that such a definition was neither possible nor necessary. In the U.S. view of the treaty's language on Article II, he stated:

While the general intent of this provision seems clear, and its application to cases such as those discussed below should present little difficulty, the United States believe [sic] it is not possible at this time to formulate a comprehensive definition or interpretation. There are many hypothetical situations which might be imagined and it is doubtful that any general definition or interpretation, unrelated to specific fact situations could satisfactorily deal with all such situations.

Some general observations can be made with respect to the question of whether or not a specific activity constitutes prohibited manufacture under the proposed treaty. For example, facts indicating that the purpose of a particular activity was the acquisition of a nuclear explosive device would tend to show non-compliance. (Thus, the construction of an experimental or prototype nuclear explosive device would be covered by the term 'manufacture' as would be the production of components [I think it is tricky but worthwhile to cite perhaps examples of non-nuclear components, some with weapons applications, some without] which could only have relevance to a nuclear explosive device.) Again, while the placing of a particular activity under safeguards would not, in and of itself, settle the question of whether that activity was in compliance with the treaty, it would of course be helpful in allaying any suspicion of non-compliance.

It may be useful to point out, for illustrative purposes, several activities which the United States would not consider per se to be violations of the prohibitions in Article II. Neither uranium enrichment nor the stockpiling of fissionable material in connection with a peaceful program would violate Article II so long as these activities were safeguarded under Article III. Also

[19] On this and related issues, see Avner Cohen and Joseph F. Pilat, "Assessing Virtual Nuclear Arsenals," *Survival*, **40**(1), Spring 1998.

clearly permitted would be the development, under safeguards, of plutonium fueled power reactors, including research on the properties of metallic plutonium, nor would Article II interfere with the development or use of fast breeder reactors under safeguards.[20]

Foster's testimony recognized that defining manufacture should in no case adversely affect peaceful nuclear activities. As a consequence, there was a clear interest in ensuring that the prohibitions in Article II not be interpreted as including sensitive nuclear activities such as reprocessing, enrichment, plutonium-fueled power reactors, and fast breeder reactors. This understanding of Article II affects the reading of Article IV and is in effect an endorsement of nuclear latency, although it was viewed in the context of the basic bargain of the treaty—peaceful nuclear power cooperation in exchange for verified pledges not to misuse peaceful programs for nuclear weapons or other explosive devices.

This interpretation has been the accepted U.S. view on the interpretation of Article II, which George Bunn's 1970 assessment made clear. Bunn argued that, for Articles I and II, "'[m]anufacture' . . . would clearly include the construction of an experimental or prototype nuclear explosive device, or of components that could have relevance only to such a device. It would clearly not include the production of fissile material or the construction of a reactor in a peaceful program under the safeguards required by other articles of the treaty."[21]

During Article II negotiations, there was little discussion of this matter, and a number of formulations were proposed but not adopted. The Soviet draft of September 24, 1965, envisaged undertaking by NNWS not to "prepare for the manufacture" of nuclear weapons.[22] The U.S. draft of March, 21, 1966, included preparations for manufacture but only in the context of prohibitions on assistance under Articles I and II. Under that formulation, NNWS would be allowed to make indigenous preparations for the manufacture of nuclear weapons, provided that the preparations did not include violation of safeguards on nuclear material.[23] Sweden argued that waiting until a state demonstrated it possessed nuclear weapons was too late, but worried about adversely affecting R&D. The Swedish negotiator asked where the line could be drawn in the "long ladder" of steps toward manufacture, stating: "Already to probe the thinking of politicians and the laboratory research of scientists . . . would be undesirable intervention."[24]

As for Article III.1, the text begins with a broad statement of purpose, but then narrows its focus to nuclear material. It appears that this was intended, and the fact that the 1967 treaty of Tlatelolco, for nonproliferation in Latin America and the Caribbean, has a very different approach reinforces this interpretation. The scope of the Tlatelolco treaty's safeguards extends explicitly beyond nuclear material. Article 12 states: "The Control System shall be used in particular for the purpose of verifying (a) That

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[20] "Extension of Remarks by Mr. Foster in Response to Question Regarding Nuclear Explosive Devices, Hearings on the Treaty on the Nonproliferation of Nuclear Weapons," Senate Rep. No. 9, 90th Congress, Second Session, 1968.

[21] George Bunn, "Horizontal Proliferation of Nuclear Weapons," in *Nuclear Proliferation: Prospects for Control*, Bennett Boskey and Mason Willrich, eds. (New York: Dunellan, 1970), 31.

[22] "International Negotiations on the Treaty on the Nonproliferation of Nuclear Weapons," U.S. Arms Control and Disarmament Agency, 1969, 135–136. On the draft, see also *Bulletin of the Atomic Scientists*, January 1967, 42.

[23] See Mohamed I. Shaker, *The Nuclear Non-Proliferation Treaty: Origin and Implementation* (London, Rome , New York: Oceana, 1980), vol. I, 249.

[24] "International Negotiations on the Treaty on Nonproliferation…" 56–57. See also Shaker, *Nuclear Non-Proliferation Treaty*… 249.

devices, services and facilities intended for peaceful uses of nuclear energy are not used in the testing or manufacture of nuclear weapons."[25] This is not the case with IAEA safeguards under the NPT.

As suggested, at the time of the NPT negotiations, Article IV was seen to protect the development of even the most sensitive technologies as an "inalienable right" under the treaty. Since then, Article IV has to some degree been reinterpreted by the U.S. and other states following the Indian test in 1974 and more recently following Iranian and other cases of noncompliance.[26]

While the original meaning of the NPT text is important, the issues facing interpretations of Articles II, III, and IV today have changed in the aftermath of the noncompliance debate and efforts to address it over the last 20 years. Yet there will be little prospect of addressing R&D in a meaningful way. Article 2 of the 1997 Additional Protocol (AP) requires that a state provide a "general description of nuclear fuel cycle-related research and development activities." However, the requirement is limited in various ways and Article 18 defines nuclear fuel cycle-related research and development activities as ". . . those activities which are specifically related to any process or system development aspect of any of the following:

- conversion of nuclear material,
- enrichment of nuclear material,
- nuclear fuel fabrication,
- reactors,
- critical facilities,
- reprocessing of nuclear fuel, processing (not including repackaging or conditioning not involving the separation of elements, for storage or disposal)of intermediate or high-level waste containing plutonium, high enriched uranium or uranium-233,

but do not include activities related to theoretical or basic scientific research or to research and development on industrial radioisotope applications, medical, hydrological and agricultural applications, health and environmental effects and improved maintenance."[27]

Driven by the need to deal with noncompliance, the AP recognized the need for information about a state's R&D. The authors of the NPT had believed that R&D cannot be effectively controlled or verified. Further, they felt that any attempt to control knowledge and experience would adversely affect scientific freedom and progress as well as national sovereignty.

Those parameters made it possible for the NPT regime to be used to develop latent capabilities as a hedge. To some extent, the difficulties of dealing with the nuclear-armed, non-NPT states and noncompliant NPT parties have led most observers to see latency as a distinctly preferable alternative to openly testing or declaring a nuclear capacity. Others worry about the effects of maintaining ambiguity on prospects for controlling and ensuring the safety and security of undeclared arsenals. In either case, few have entirely

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[25] *Treaty for the Prohibition of Nuclear Weapons in Latin America and the Caribbean (Treaty of Tlatelolco),* http://www.opanal.org/opanal/Tlatelolco/Tlatelolco-i.htm - 14.

[26] See, for example, Lawrence Scheinman, "Article IV of the NPT: Background, Problems, Some Prospects," No. 5, prepared for the Weapons of Mass Destruction Commission, June 7, 2004, http://www.wmdcommission.org.

[27] The text of the Model Additional Protocol is available at http://www.iaea.org/Publications/Factsheets/English/sg_overview.html.

given up the effort to reduce latency, especially in states of concern. Among the proposals to address this difficult issue, multinational approaches need to be explored.[28]

Disarmament and Latency

In recent years, nuclear arms control agreements, including deep cuts in nuclear arsenals, the Comprehensive Test Ban Treaty, and the proposed fissile material cutoff, have not directly addressed knowledge and experience, i.e., latency, nor are they likely to do so in the future. In the view of at least some disarmament proponents, the potential value of latency is to reduce, if not eliminate, any residual risk for states to reduce or eliminate their nuclear arsenals. Latent capabilities could thus in principle promote arms control and disarmament objectives by providing a hedge to nuclear weapon states deciding whether to retain or disavow them. By hedging against future threats, latent capabilities could allow a state to contemplate greater risks in reducing or eliminating its arsenal. These arguments are receiving greater attention today as interest in disarmament has grown in recent years. If there is progress toward the goal of disarmament, the latency issue will be at the fore.

States that once had active nuclear weapon programs and those with advanced nuclear power programs will both have some degree of nuclear capability, regardless of their decisions on disarmament. The assumption generally is that latent capabilities enable disarmament, and that nuclear weapon states can choose whether or not to rely on these capabilities as a hedge against disarmament. In any future disarmament agreement, such capabilities could be merely recognized, sanctioned and preserved, or proscribed and dismantled to the extent possible.

If virtual capabilities (without forces in place) are to serve as a hedge—albeit one of uncertain value—human capital and facilities can not be mothballed, and they will need to be exercised, which may appear threatening. In addition, if such an approach is to be pursued, it will require a stockpile stewardship program similar that called for in the 2010 Nuclear Posture Review (NPR). The NPR called for a sound stockpile management program for extending the life of U.S. nuclear weapons in order to ensure a safe, secure, and effective deterrent without the development of new nuclear warheads or further nuclear testing. It declared that "the United States will not develop new nuclear warheads. Life Extension Programs (LEPs) will use only nuclear components based on previously tested designs, and will not support new military missions or provide for new military capabilities."[29]

The acceptance of such a strategy as "disarmament" by NNWS and nongovernmental organizations is by no means certain, and this strategy has been criticized by some abolitionists. Although modernization of the nuclear infrastructure is criticized as inconsistent with arms control and nonproliferation objectives, the NPR argues it is essential to realize those objectives:

By certifying the reliability of each weapon type we retain, the United States can credibly assure non-nuclear allies and partners they need not build their own, while seeking greater stockpile reductions than otherwise possible. Further, a corps of highly skilled personnel will continue to expand our ability to understand the technical challenges associated with verifying ever deeper arms control reductions.

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[28] While the debate over the anticipated nuclear renaissance has highlighted concerns about the use of civilian nuclear programs to launch or relaunch weapon programs, the disarmament debate has been more likely to see civil programs as a "hedge." This concept has some problems. Civil programs will provide some capability that can be used to start or restart a weapon program. They can provide the needed material, although the material may not be directly or immediately available if the program did not include enrichment or reprocessing facilities, or, if it did, may not be optimal for weapons. Multinational approaches to the fuel cycle reduce the prospects for misusing civil facilities through multinational ownership by creating multiple decision points, but they also decrease any hedge value for these facilities. Moreover, they will be on one state's soil and in a crisis can be seized or effectively circumvented by the rapid buildup of clandestine capabilities. Either path would be highly destabilizing.

[29] *Nuclear Posture Review Report* (Washington, D.C.: U.S. Department of Defense, April 2010).

Through science and engineering programs that improve the analysis of the reliability of our warheads, we also enhance our ability to assess and render safe potential terrorist nuclear devices and support other national security initiatives, such as nuclear forensics and attribution. Expert nuclear scientists and engineers help improve our understanding of foreign nuclear weapons activities, which is critical for managing risks on the path to zero. And, in a world with complete nuclear disarmament, a robust intellectual and physical capability would provide the ultimate insurance against nuclear break-out by an aggressor.[30]

Moreover, by modernizing the aging U.S. nuclear weapons-supporting facilities and investing in human capital, the NPR argued, "the United States can substantially reduce the number of stockpiled nuclear weapons we retain as a hedge against technical or geopolitical surprise, accelerate the dismantlement of nuclear weapons no longer required for our deterrent, and improve our understanding of foreign nuclear weapons activities."[31]

Verification of deeper cuts and disarmament will be complicated by the latency that will exist in a world without nuclear weapons, as well as by the perceived need to maintain latency. Yet the verification of dismantlement or the elimination of nuclear warheads and components is probably the most pressing problem of moving toward zero, however defined, even without the latency complication. The considerable R&D in the U.S. and elsewhere, on warhead and dismantlement transparency/verification since the early 1990s reveals the enormity of the problems and the challenges of developing effective capabilities to verify very small arsenals, let alone "zero."

The U.S. has focused on developing attribution measurement systems to determine whether an item is like, or consistent with, a nuclear weapon (e.g., mass and isotopic ratios) and information barrier systems to prevent direct inspector or third party access to these measurements. However, they have serious technical challenges, including the need to address authentication and transparency, among other issues. Considerable work on verification schemes have followed an item through the dismantlement process. These verification schemes are limited, especially by the uncertainties concerning the item at the point of entry, wherever that may be, by the possibility of illicit activities that may occur during the process, and by potentially overwhelming costs. These and other issues make it challenging to ensure that an item brought into the verification system is a weapon, is fully consistent with being a weapon, or has a "weapon origin." This challenge could raise questions about whether one is genuinely addressing warheads and their dismantlement directly.

These verification issues all derive from the classic tension between the desired opacity of nuclear weapon information and the transparency essential for verification. Some problems are increasing as weapons move from deployed status to increasingly consolidated storage, which can affect the value of chain-of-custody procedures for verification. Limits on access and different classification systems among states are a few other issues. Latency only exacerbates the situation and raises questions about possible solutions.

Dismantling and eliminating warheads, nuclear material, and facilities to achieve disarmament as part of regional nonproliferation "rollback" scenarios would be difficult enough. Incomparably more challenging would be addressing the nuclear weapon knowledge and experience held by the scientists and engineers who had developed, tested, produced, and deployed nuclear weapons and could be expected to do so once again.

Conclusions

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[30] Ibid.

[31] Ibid.

Nuclear latency shares some latency issues with other dual-use technologies, but it has unique elements. At the outset, nuclear technology was seen to be in itself revolutionary with the threat of strategic surprise to some degree inherent in the technology. Although a small arsenal, even a single weapon, is not seen in the same way it was in the 1940s, there remains a concern that some limited number of weapons could dramatically change the strategic equation. Nuclear latency thus remains a concern and will continue to even if nuclear disarmament is achieved.

Latency is a reality for both nuclear weapon states and for many nonnuclear weapon states today. Latency has already provided some level of virtual nuclear weapon capability as a result of spreading nuclear energy technologies and programs. Nuclear capabilities are now widespread and will increase with nuclear power programs, especially those that involve direct-use nuclear materials such as plutonium and highly enriched uranium. Capabilities for weaponization, delivery, and support provide an indicator of intent, albeit one with low visibility and high ambiguity.

It is a given that latency will exist in a nuclear weapon-free world. Shutdown nuclear weapon programs can be reconstituted, and civil nuclear programs can be used, or misused, to make weapons by states and possibly even nonstate actors. In this case, latency can in principle make a mockery of nonproliferation efforts by creating doubts about the effectiveness and credibility of the nonproliferation regime. In the disarmament arena, latency can offer a reduced risk of accidental or unauthorized use on the positive side as well as allow a high level of crisis instability and the prospect of disarmament being rapidly reversed.

Latency can be a strategy for states, including some proliferants who will find ambiguity to be the optimal response for addressing their perceived security threats while avoiding international reactions from diplomatic isolation to sanctions to military action. At any point short of a global zero, most nuclear powers would likely view reliance on latent capabilities as posing unacceptable risks. Even in a nuclear weapon-free world, politicians and bureaucracies would be resistant to any regime lacking a developed protocol that precisely delineates prohibited capabilities. The protocol would also have to ensure that allowed capacity is not asymmetric and could be fully resourced and exercised. There is no question that at least some aspects of such an arrangement would be essentially unverifiable and would have to be addressed as a cooperative or confidence-building measure.

These and other issues make it highly unlikely that any broad agreement on latency will be possible until the later and perhaps final stages of a regional security accord or until the world is well on the path to global zero. Latency could, in principle, have a role in providing some level of assurance to states that give up nuclear capacities in pursuit of nonproliferation or disarmament at the regional or global stage. However, it will be an uncertain assurance at best.

Technology Case Studies, an Introduction

by Michael Nacht

The second section of this volume presents four technology case studies. As with the country case studies in the section that follows, these cases are intended to be illustrative rather than comprehensive of how technology-specific latency can be exploited. By coupling the cases in this technology section with the country cases in the next section, the reader can gain an appreciation for the range of options available to governments and nonstate actors to develop latent capabilities with strategic implications.

Dr. Robert Yamamoto offers a comprehensive assessment of laser technology, exploring its dual-use dilemma. For military applications, he notes that laser–target interaction is affected by laser characteristics, weather conditions, target and tracking features, and how the kill assessment is determined. He reviews key laser technologies from high-power diode arrays to laser gain media to adaptive optics, and he concludes with an overview of possible new uses for high-power lasers and the barriers to entry for their development.

Dr. Robert Manning explores the impact of robotics on the "third industrial revolution." Manning notes that the new era in robotics relates to the unfolding interaction within the information and communication technology revolution, improvements in artificial intelligence, sensing technology, and the digital economy. As measured by robot density per 10,000 employees in developed societies, he notes that Japan is far in the lead and China trails far behind, with Italy, Germany and the U.S. in between. The chapter concludes with an exploration of alternative futures for robotics' social and economic policy implications, reviewing both optimistic and pessimistic perspectives.

Dr. Richard Silberglitt offers a highly detailed examination of the paths and barriers to technology forecasting. He poses the following question: If technology is the expression of our aspirations, capabilities, and actions, why is there still great resistance to technology foresight and planning? Silberglitt offers a theoretical explanation based on the concepts of "persistence" and "alignment" to understand how biological systems evaluate, adapt, and reject nonbiological (or abiotic) systems. He notes that "synthetic" and "analytic" expertise are required for foresight (e.g., the farmer has the former to avoid having his crops fail; the weather forecaster has the latter to appreciate that weather is changing). He offers numerous insights about how "persistence" and "alignment" interact and notes that "alignment is nonjudgmental, being a fundamentally recursive, optimizing algorithm, whereas persistence applies a foundation upon which virtue should apply to what is built."

The final technology chapter, by Dr. Banning Garrett, deals with the amazing potential of 3D printing, and the opportunities and dangers it presents for strategic latency. Garrett notes its special characteristics ranging from increased product design freedom (no cost for complexity) to simplification of manufacturing processes and the potential for instant production on a global scale. An added plus is the reduction of waste and emissions because 3D printing technology is a naturally "green" technology. The author points out, however, that malevolent actions are also now feasible, such as nonstate actors producing improvised explosive devices far more easily.

The intent of these chapters is to illustrate how latent technological potential is being tapped, channeled, and anticipated.

Lasers and Latency: The Dream Continues

by Robert Yamamoto

Since its creation over 50 years ago by Theodore H. Maiman,[1] the laser (light amplification by stimulated emission of radiation) has come to affect many facets of our everyday lives. Uses include the laser pointer during countless academic, government, and business presentations, lasik (laser-assisted in situ keratmoileusis), a refractive eye surgery to correct vision problems, and, of course, the infamous destruction of the planet Alderaan by a high-power laser from the Death Star. This third example is obviously a fictional application from the first *Star Wars* movie, but one that many a movie-goer will remember.

A weaponized laser would bring to the battlefield nearly instant, extremely precise strikes against an enemy. Billions of dollars were poured into the Reagan administration's "Star Wars" laser weapons missile defense and into similar programs since. Yet the dream of a laser as a serious military weapon has yet to be fulfilled. Even with some of the best and brightest scientific and engineering minds working on the problem, lasers find only very limited use on the battlefield. Are laser weapons truly nothing but hype? Will the latent military potential of lasers ever be a reality?

Thus far, industry has found no use for a laser of 100 kilowatts, the "holy grail" for a laser weapon. Laser cutting and shot peening, for example, require just a few kilowatts. The oil and gas industry is exploring the use of high-power laser-mechanical drilling, but in this case "high power" is in the range of 20 kilowatts.[2]

Researchers have proposed other uses, and new ideas are plentiful. Lawrence Livermore National Laboratory scientists have proposed using a high-power laser for plant eradication. Their proposal for a laser guide star has come to fruition at several astronomical observatories. For the environmentally clean destruction of an opium poppy field, for example, a solid-state laser system would be mounted on the underbelly of an aerial platform. As the platform crosses back and forth across a large poppy field, the laser irradiates the poppies below. The optimal time for irradiation is during blossom growth. The high temperature from the diode laser beam promotes tissue damage of the tender blossom, stunting its growth and killing the blossom altogether.[3]

The guide star, an artificial "star" to enhance astronomical adaptive optics imaging, uses a laser beam to establish a steady and reliable reference point (i.e., a star) with an explicitly known location. Using this guide star as a fixed point of reference, other objects of interest can be more accurately located , allowing researchers to map the heavens and focus on distant phenomena.[4] Sodium beacons are created by using a specially tuned laser to energize the layer of sodium atoms that are naturally present in the mesosphere at an altitude of approximately 90 kilometers. The sodium atoms then re-emit the laser light, producing a glowing artificial star. Livermore scientists have installed laser guide stars at the Lick and Palomar observatories in California and at the Keck Observatory in Hawaii (pictured below), with several others under development. The ability to navigate throughout the universe using lasers as headlights raises new possibilities for space travel and exploration.

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[1] Theodore H. Maiman, *The Laser Odyssey* (Laser Press, 2000).

[2] http://www.industrial-lasers.com/articles/2012/05/high-power-lasers-in-the-energy-industry.html.

[3] Alexander M. Rubenchik et. al., "Environmentally Clean Mitigation of Undesirable Plant Life Using Lasers," Lawrence Livermore National Laboratory, LLNL-TR-414879, July 2009.

[4] Alexander M. Rubenchik et. al., "Solar Power Beaming: From Space to Earth," Lawrence Livermore National Laboratory, LLNL-TR-412782, May 2009.

Laser guide star at Keck Observatory, Hawaii

In addition, high-power lasers are used extensively in research at Lawrence Livermore's National Ignition Facility (NIF), at the University of Rochester's Omega laser, and other lasers around the world. NIF, the European HiPER laser, and other laser projects are also pursuing the goal of inertial confinement fusion for virtually endless energy production.

Each of these applications is very different, yet from a high-power laser perspective, they look basically identical. They all require:

- Megawatt-class laser.
- High-quality optical tracking and alignment system.
- Efficient and effective atmospheric propagation.
- Self-contained power system.
- High reliability.
- Very low maintenance and a long lifetime.

To date, no one has put all of these pieces together effectively. But that hasn't stopped research groups from trying.

A Multitude of Design Possibilities

Livermore's solid-state NIF is the largest, most powerful laser in the world. It is the size of three football fields and can create a single 500-terawatt peak flash of light about once every six hours. The time between shots is required for cooling of laser components (i.e., for thermal management). NIF is an excellent tool for experiments in high-energy-density science for stockpile stewardship of the U.S. nuclear weapons arsenal and for experiments leading to fusion ignition, but clearly NIF-style technology is not a candidate for a laser weapon.

Over the years, national laboratories and defense contractors have explored several options, including chemical, solid-state, fiber, and free-electron laser systems. Several approaches have successfully demonstrated proof of concept, but none has been worthy of full adoption. Practical considerations of cost, weight, and reliability under variable conditions have prevented the full military potential of laser weapons from being realized.

For example, the joint U.S.-Israeli Tactical High-Energy Laser[5], a deuterium–fluoride, chemical laser system, shot down Katyusha rockets, heavy rockets, and artillery shells in the early 2000s. But the prototype was roughly the size of six city buses, and in 2005, the U.S. and Israel discontinued its development.

The U.S. Air Force had high hopes for its Airborne Laser Testbed, which was designed to catch ballistic missiles in their boost phase. (See CNET for a brief history of laser weapons.)[6] The system found some success on various test ranges in 2010 and 2011, and a similar system was designed to destroy a variety of ground targets. However, the Defense Department cancelled the program in 2011, citing the impracticality of deploying scores of laser-armed 747 jets against hard-to-find targets such as Iranian missiles. Chemical lasers offer high power. However, for the most part, because of their cost and complexity, chemical lasers have lost their luster, and researchers have turned to other architectures.

In 2009, Northrop Grumman's Joint High Power Solid-State Laser (JHPSSL) was the first solid-state laser system to achieve the necessary 100 kilowatts, or 100,000 watts, to be considered a weapons-grade laser.[7] In 2011, the U.S. Navy demonstrated a solid-state laser gun to track and defeat multiple moving small boat targets at operationally significant ranges.[8] But there are doubts that the Maritime Laser Demonstration can achieve the necessary 100 kilowatts.[9] Efforts continue to improve the power and efficiency of the JHPSSL and its variants.

In 2005, the Defense Advanced Research Projects Agency began developing the High Energy Liquid Laser Defense System (HELLADS), which is designed to counter rockets, artillery shells, and mortars. It is to be a 150-kilowatt laser with a volume of 3 cubic meters and a weight of no more than 5 kilograms per kilowatt (1650 pounds). A unique cooling system is designed to cool the laser at the same time that the gun is firing.[10] With this thermal management system, HELLADS is designed to fire continuous beams. In contrast, solid-state lasers are more intense but must be fired in pulses to keep them from overheating. In 2012, the HELLADS system completed laboratory testing and advanced to the final development phase.[11]

Meanwhile, the Department of Defense is pursuing a Robust Electric Laser Initiative (RELI), which is meant to create next-generation, lightweight, compact laser weapons for close-in battlefield use.[12] Lockheed Martin's Aculight, to be used in RELI, is a compact fiber laser system capable of producing 100 kilowatts. Fiber lasers tend to need less power to operate, and optical fibers can provide nearly perfect quality beams by confining the light within the fiber's glass structure. However, several other defense

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[5] http://www.northropgrumman.com/Capabilities/ChemicalHighEnergyLaser/TacticalHighEnergyLaser/Pages/default.aspx, accessed September 24, 2013.

[6] http://news.cnet.com/2300-11386_3-10012168.html, accessed September 19, 2013.

[7] http://www.northropgrumman.com/Capabilities/SolidStateHighEnergyLaserSystems/Pages/JointHighPowerSolidStateLaser.aspx, accessed September 19, 2013.

[8] http://www.northropgrumman.com/Capabilities/SolidStateHighEnergyLaserSystems/Documents/MLD_Datasheet.pdf, accessed September 24, 2013.

[9] http://www.wired.com/dangerroom/2013/03/navy-2013-laser//, accessed October 1, 2013.

[10] http://www.space.com/1496-darpa-star-wars-style-laser-cannon.html, accessed September 24, 2013.

[11] http://www.darpa.mil/Our_Work/STO/Programs/High_Energy_Liquid_Laser_Area_Defense_System_%28HELLADS%29.aspx, accessed September 24, 2013.

[12] http://www.foxnews.com/tech/2013/08/15/laser-weapons-inch-closer-to-battlefield//, accessed September 24, 2013.

contractors are also on the hunt for smaller, battlefield lasers. Boeing has been awarded a U.S. Navy contract to develop a free-electron laser weapon system for an ultraprecise laser gun to defend U.S. ships.[13]

The U.S. Army and Navy both have solid-state laser weapon systems under development for use against incoming projectiles. The Army has the High Energy Laser Technology Demonstrator (HELTD), and the Navy's is the Laser Weapons System (LaWS).[14,15] LaWS has demonstrated the ability to shoot a drone out of the sky, and it is scheduled to be deployed on the USS Ponce as an antimissile system in 2014.[16]

A few nonlethal laser systems are also being used or considered for use by the military. Laser sighting and pointing systems are in wide use. One new system is the Mk 38 Mod 2 Machine Gun System with Tactical Laser System for the Navy. It is a fiber laser system that will be mounted on the MK 38 machine gun for more effective detection, tracking, classification, and engagement of the target.[17] The Green Laser Escalation of Force (GLEF) is meant to "dazzle" the enemy, making it hard for the combatant to aim a weapon. GLEF could also be used to keep a civilian from inadvertently wandering too close to a checkpoint where deadly force might be used. The Army sent GLEF to Afghanistan for evaluation in 2010, and similar systems were earlier used in Iraq.[18]

This listing of current research and development activities is by no means complete. However, it illustrates the variety of systems that have been considered and some of the challenges that remain.

Technological Hurdles

For any of the proposed laser systems, dozens of factors must work together perfectly, and clearly we aren't there yet. Just a few include:

The Laser:

- How powerful is the laser? The more powerful the laser, the more energy transmitted to the target, everything else being equal.
- How well does the laser propagate through the atmosphere? Certain laser wavelengths travel through different forms of atmosphere better than others.
- How long can the laser fire? The laser must be able to engage the target for a minimum period of time.

Weather/Atmosphere:

- What are the weather conditions? A laser generally travels farther on a clear and calm day rather than on a foggy, rainy, or windy day.

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[13] http://boeing.mediaroom.com/index.php?s=20295&item=1126,accessed September 23, 2013.

[14] http://missiledefense.wordpress.com/tag/heltd//, accessed September 19, 2013.

[15] http://www.gizmag.com/laser-laws/26978//, accessed September 23, 2013.

[16] http://www.businesswire.com/news/home/20110830006162/en/BAE-Systems-Completes-Successful-Test-Mk-38, accessed September 23, 2013.

[17] Ibid.

[18] http://news.cnet.com/2300-11386_3-10012168-23.html, accessed September 19, 2013.

The Target:

- What type of destruction mechanism is desired? Is the high explosive in the target to be heated to the point where detonation or deflagration occurs, or is the goal to damage the engine or some aerodynamic structure of the target?
- What are the material properties of the target? For example, a metal target will likely heat more rapidly than a nonmetallic target.

Target Acquisition and Tracking:

- How fast is the target moving? A fast moving target may be harder to track once acquired, making it more difficult for the laser to be directed onto the target.

Kill Assessment:

- What are the indicators of target destruction? Does the target burst into flames, explode into hundreds of pieces, or simply miss its objective?

Notice that achieving necessary power is the first on the list, and it continues to be the primary hurdle. From a strictly pragmatic mechanical engineering perspective, a laser is nothing more than a heat-generation machine, and not a particularly efficient one. Current solid-state lasers producing kilowatt-class power levels—the level required for a laser weapon—have "wall-plug" type efficiencies of up to 30 percent.

Thus, in a best-case scenario, only 30 percent of the total source energy is actually converted into laser light, with the remaining 70 percent simply dissipated as waste heat. How the laser's thermal management system resolves the removal of this large amount of heat—from both time and space perspectives—directly correlates to the quality of the laser beam produced and to the effectiveness of the laser system. Livermore's enormously powerful NIF laser delivers from 10 to 20 percent of its laser energy to a target capsule and has a net wall-plug efficiency of less than 1 percent. Given a maximum of 30 percent efficiency, and possibly much less, a 100-kilowatt laser requires an energy source as much as three orders of magnitude larger, or 1 megawatt. This requirement places significant limitations on their use as battlefield weapons.

Livermore has pursued the science of the solid-state laser for decades, in particular the development of technologies aimed at maximizing power output. Reliable and cost-efficient high-power diode bars are one example. Tens of thousands of these diode bars are required, which necessitates high-volume production manufacturing techniques with corresponding quality control and quality assurance. Another example is the media used for laser optics, which amplify and maximize the power of the light that passes through the system. Continuing research indicates that ceramics are an improvement over the single crystals used for decades.

A third technology—adaptive optics—uses dozens of actuators to manipulate a deformable mirror and correct for heat-induced aberrations. Correcting a laser beam provides a more uniform and intense beam profile and thus a more powerful beam. Adaptive optics would play a critical role in propagating a laser beam cleanly through the atmosphere and has a multitude of other applications that have benefitted from the research and development conducted for its use in NIF.

Comparable technological advances need to be made to make a free-electron or fiber laser weapon system operate effectively.

Higher Hurdles

In the end, sheer cost and Mother Nature stand in the way of achieving a fieldable laser weapon given current technology. A 100-kilowatt laser could require as much as 1 megawatt of prime power, which equates to both cost and space challenges. For a solid-state laser, the cost for the high-power diode arrays alone could be as high as $20 million if not more per laser system. In comparison, the cost of an M1A1 Abrams tank is about $7.5 million. With decreasing budgets and tremendous competition for government funds, the dollars required to produce this type of laser system are not readily available. Private industry seems unwilling to invest the large sums of money required, based on the perceived small return on investment, at least in the short term.

The 100-kilowatt or larger laser, whether used to blast rockets, artillery, and mortars out of the sky or for basic scientific research, simply has not come to fruition. At these power levels, Mother Nature is very unforgiving from a thermodynamics perspective. As the output power increases, so does the amount of waste heat generated. Removing hundreds, if not thousands, of kilowatts of waste heat in real time while simultaneously producing a high-quality output laser beam has not been practically demonstrated.

There is also a lack of understanding, even by alleged experts, of what performance is really required and what can realistically be achieved today by a high-power solid-state laser. Even as the laser passes the half-century mark, for all intent and purposes this is a brand new technology from a military perspective.

Rising Robotics and the Third Industrial Revolution

by Robert A. Manning

Seven years ago, Bill Gates created a buzz in the high-tech community when he published an article in *Scientific American* suggesting robotics was becoming the next "new thing." Entitled "A Robot in Every Home,"[1] the Microsoft cofounder's essay argued presciently that the state of robotics paralleled that of the computer industry in the 1970s when it approached a tipping point, launching the PC revolution.

Just as Gates' own innovative software, Moore's Law (the exponential increase in processing capacity and lowering of the cost), and then the Internet spawned ubiquitous personal computers, several trends are converging to push robotics to a new level, becoming widely accessible to household consumers. Until now, the vast majority of industrial robots, more than 70 percent, have been used in auto assembly plants and more recently in electronics assembly. There have been no standards or software applications for wide use in robotics, as was the case for personal computers in the 1970s. Each industrial task robot—a device with three or more axes of motion (think hand, wrist, elbow) reprogrammable for different tasks—has had to be individually developed.

Robotics is at an inflection point. The new era in robotics and automation that is beginning to unfold is part of the larger information and communication technology (ICT) revolution, steady improvements in artificial intelligence (AI), sensing technology, and the digital economy (is not an ATM a type of robot?). Indeed, robotics' rise is a by-product of a transformation that has been dubbed the Third Industrial Revolution (the first was the application of steam power to production in the late 18th century and the second was the invention of the modern assembly line in the early 20th century).

The Third Industrial Revolution is the convergence and synergy of ICT, robotics and AI, advanced manufacturing systems, 3D printing, nanotechnology, and big data into a highly networked, intelligent, and global knowledge-based economy. In terms of social and political impact, robotics should be viewed along with ICT and nanotechnology as an important economic enabler and a critical component of this historic technological transformation.

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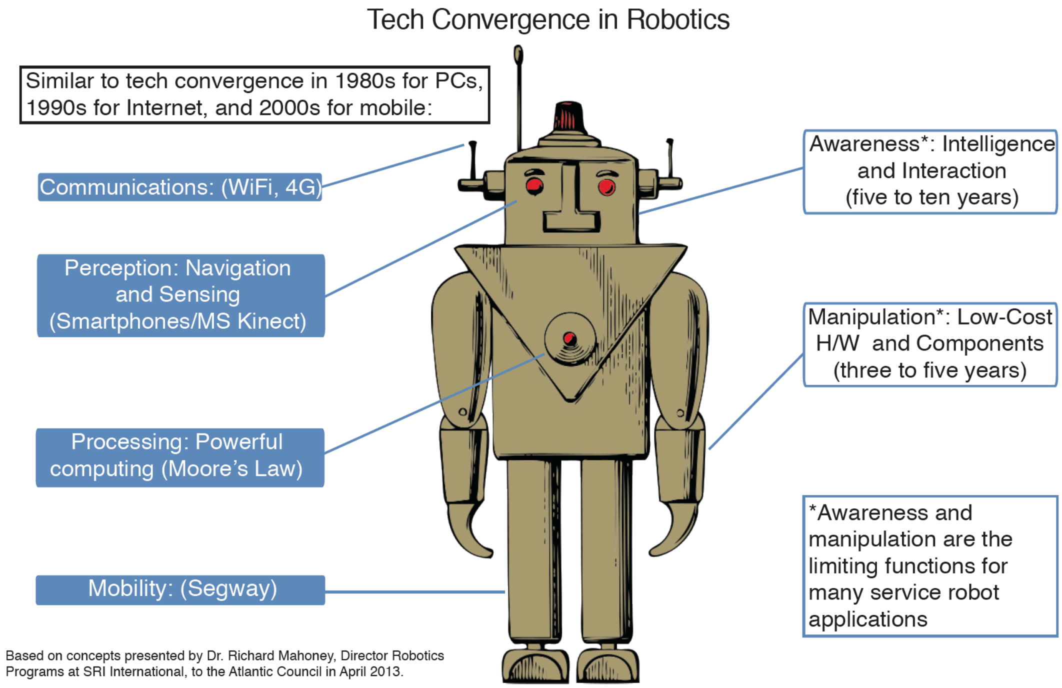
[1] Bill Gates, "A Robot in Every Home," *Scientific American*, January 2007.



The Next Phase

The advance of robotics, like the U.S. shale revolution, is the result of substantive research and development (R&D) efforts of governments, businesses, and universities over the past two decades. In the U.S., the Defense Advanced Research Projects Agency (DARPA) and NASA; in Japan, FANUC Corporation and government funding; in South Korea, the Ministry of Knowledge Economy and firms such as Samsung and LG; and in Europe, firms such as ABB and the European Network of Robotic Research have driven investment for improvements in hardware (e.g., prehensile hand movements) and software. South Korea has invested $100 million annually since 2002, and Japan is investing $350 million over the next 10 years into humanoid robots alone. The European Commission has invested $600 million into robotics and cognitive systems in its Seventh Framework Program and plans $900 million for manufacturing and robotics in its Horizons 2020 program. DARPA, with a $2.8 billion annual budget, has driven much robotics innovation, and the U.S. National Robotics Initiative, playing a venture capitalist role, is investing in dozens of robotics projects, from its driverless car and robotics challenges, to bots to disarm improvised explosive devices, or IEDs.[2]

Such investments and some remarkable contributions from small U.S. startups are driving prices for robots down exponentially (from the $200,000–$300,000 range to $22,000 or less)—with ever faster and more sophisticated algorithms, sensor technology, and AI. The result is more capable machines both qualitatively and quantitatively and at much lower cost.

From now until 2030, we will move from Roomba vacuum cleaners, robot lawn mowers, single-task industrial hand machines, and unmanned aerial vehicles to self-driving cars and personal service robots.

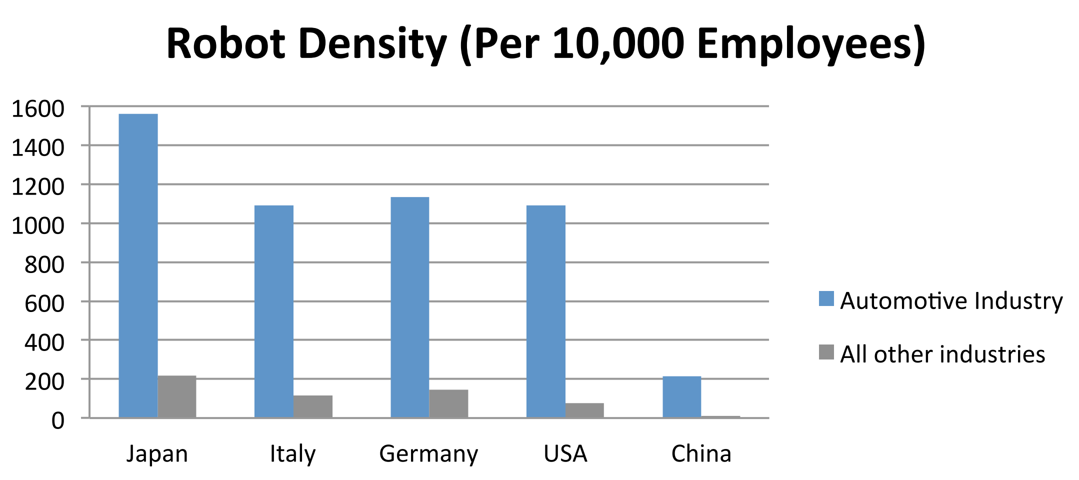
Robotics has been a driver of "inshoring," returning manufacturing to the U.S. There are approximately 120,000 industrial robots in the U.S., just behind Japan and Italy. Extrapolating from 2011 statistics of the International Federation of Robotics, there are in excess of 1.4 million operational industrial robots

[2] See "A Roadmap for U.S. Robotics: From Internet to Robotics," an academic consortium sponsored by Robotics in America, March 19, 2013.

worldwide.[3] Beginning from a concentration in the auto industry, robotics has begun to spread to electronics assembly and increasingly to food and beverage and other packing, distribution, and shipping operations.

In a dramatic example of how robotics is transforming the workplace, FOXCONN, which employs 1.2 million in China and assembles some 40 percent of the world's consumer electronics, has announced it will purchase 1 million robots over the next three years.[4] Increasingly, jobs that require low-skilled, repetitive physical labor will be done by robot, in what can be considered a qualitative leap in the pace of automation that some have compared to the economic transformation at the beginning of the 20th century. At that time, the workforce engaged in agriculture in the U.S. dropped from 40 percent to 2 percent as industry took off and agriculture became mechanized.[5]

The chart below depicts current robot deployment and also suggests the growth potential for the use of robots.



Source: Data compiled through 2012 from IFR World Robotics 2013 Industrial Robots

The Tipping Point

Two new developments are emblematic of the tipping point of exponential growth—in both quantity and quality—that robotics is nearing. The first is Willow Garage, a startup founded by former Google architect Scott Hassan in 2006, which developed the first open-source common Robot Operating System (ROS), now widely disseminated to researchers and industry. The ROS is the sort of enabling technology that may lead to qualitative leaps in robotics capabilities. In addition, Willow Garage developed a two-armed, wheeled, human-size robot called PR2, an R&D tool that facilitates robotics innovation and can use the ROS software.

The second emblem of change is Baxter, a next-generation mobile, human-like robot that can work alongside humans, created by Rodney Brooks, the inventor of the Roomba robot and now chief

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[3] IFR website, www.ifr.org, statistics 2012.

[4] Xinhua News Service, July 30, 2011, http://news.xinhuanet.com/english2010/china/2011-07/30/c_131018764.htm.

[5] For a compelling argument on robotics and the future of work, see Erik Brynjolfsson and Andrew Mcaffee, *Race Against The Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibly Transforming Employment and the Economy*, Kindle Edition, 2011.

technology officer of Rethink Robotics, a startup launched in 2008. Baxter is a breakthrough because of what it can do, its ease of use, its smartness, and perhaps most dramatically, its cost. It has two arms and cartoon eyes in a screen interface that provides feedback to users. Its arms have seven axes of motion, and it has a mechanism called an elastic actuator that enables it to respond: its arm will stop if touched and will follow human motions.

Baxter's ability to respond to human input allows it operate in an unstructured environment. It can pick up and move things and respond to changes in its surroundings. Its cameras and sensors give Baxter a breakthrough learning ability such that anyone can "program" it: Baxter mimics its user's movements. Once shown various motions and sequences, it will repeat them. But perhaps the biggest innovation is the cost. Unlike many industrial task robots that may cost upward of $300,000, Baxter sells for $22,000.

This sort of price point changes the market. Similarly, telepresence robots available for as little as $15,000, can be used in hospitals and offices to allow a remote mobile presence. Moreover, Rethink Robotics sees Baxter as a platform similar to PCs in that it plans to upgrade software so that Baxter can adapt to the needs of its consumers' required tasks.

Variations on Baxter's capabilities are emerging. ABB has a prototype dual-armed robot for precision assembly. Kawada Industries in Japan has its Nextage robot with variable arm movements designed for assembly but at a much higher price than Baxter. Moreover, a number of small startup firms have developed robot arms. Some more expensive devices offer more precision than Baxter but not yet the versatility.

In all these developments, one can glean a glimpse of the future of robotics. Consider an upgraded version of Baxter mated with the intelligence capacity demonstrated by IBM's Watson. You can imagine the sophisticated tasks that could be performed.

Robots are increasingly part of what has been called a digital "second economy" of computers and networks that can perform services independent of most human activity—as in swiping a credit card, buying an online product or service, or getting an airline boarding pass online.[6] Computers, the Internet, and networks combined with increasingly sophisticated robotics have begun to transform the workplace. These technologies have already moved beyond replacing such low-skill jobs as assembly lines, packing, and moving goods. Robots already can perform surgery. Some, like IBM's Watson, can help diagnose cancer. And constantly-improving software can translate languages and perform legal research, using "e-discovery" to sift through legal documents that otherwise might occupy an army of legal researchers.

Over the coming decade, robots will be replacing a wider array of jobs currently performed largely by humans. Warehousing, distribution, picking and packing agriculture, light manufacturing, surveillance and security (envision drone or robot teams), and data-entry and analysis jobs will all be performed largely by robots. Airplane pilots and truck drivers may also be replaced by robots.

In the service industry, health care will be populated by robots making diagnoses, delivering medication to patients, and helping take care of the elderly. Indeed, Japan's robotics industry is heavily motivated by the need for robots to help in eldercare. Given the graying demographics in Japan and other Organization for Economic Cooperation and Development nations, robots are likely to play a rapidly growing role in health care and eldercare.

Robots will be downloading and uploading information to the cloud, sometimes via built-in software programming or by computer control. Robots could thus facilitate data collection for such needs as medical analysis. Perhaps more importantly, data that robots generate on their own activities will facilitate improvements in robot behavior and capabilities. In addition to robots in dangerous situations looking

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[6] W. Brian Arthur, "The Second Economy," *McKinsey Quarterly*, October 2011.

for IEDs or nuclear contamination, some analysts forecast that by 2025 a substantial proportion of soldiers on the battlefields will be robots. Think of the movie *I, Robot* as life imitating art.

Social and Economic Policy Implications: Alternative Futures

This transformational technology, particularly robotics, poses both risks and opportunities to policy makers and to society writ large. In the past, transformational technologies tended to be part of the economic process of "creative destruction," with old jobs replaced by whole new industries. But the breadth and scope of robotics and the digital economy displacing human-performed jobs are without precedent.

While mainstream economics has focused on how technological change increases inequality in the labor market, the impact of financial crises and recession on jobs, or how globalization disadvantages low-skill workers, it has little to offer on how the unprecedented technological transformation now under way will shape jobs of the future.[7] Some jobs, including those with a need for human judgment and human interaction (e.g., policemen, teachers, coaches, counselors, doctors) and those that oversee, repair, and create technologies would appear to endure—at least for the foreseeable future. But a large realm of uncertainty remains.

A debate continues to rage among economists and social analysts, and between "techno-optimists" and "techno-pessimists," about whether this technology transformation will free humanity to new creative heights and a flourishing of civilization, or lead to a dystopia of increased poverty, purposeless, and unhappy people. The pessimists also focus on ethical, legal, and moral issues raised by the deployment of robots. While the debate is complicated by the reality of a global slowdown and recession, there are compelling arguments in both directions. And on the future social impact of the rise of robots, it is premature to draw conclusions.

Techno-optimism

The knowledge-based economy in general is not labor intensive. For example, Apple, Amazon, Facebook, Google, and Twitter have roughly $1 trillion in market capitalization, but together they employ fewer than 150,000 people—less than the number of new entrants into the American workforce every month.

On the positive side, robotics, combined with emerging technologies such as 3D printing, nanomanufacturing, nanobiotechnology, and more capable AI, may reinforce a trend toward more local, customized production, marketing, and distribution. This phenomenon may spawn entirely new industries, such as lab-manufactured food, vertical farming in cities, and other fields we do not yet imagine. The commercialization of robots will almost certainly benefit—and probably facilitate the proliferation of—small- and medium-sized industries (there are some 300,000 in the U.S., for example), and democratize the economy. Imagine a small business with a cadre of 3D printers for manufacturing a range of products and a couple of Baxter-like robots to lift, pack, and help distribute them.

"It is a safe bet," writes *Wired* magazine's Kevin Kelly, "that the highest-earning professions in the year 2050 will depend on automations and machines that have not been invented yet . . . . Robots create jobs that we did not even know we wanted done."[8] This statement is illustrative of what may be called the techno-optimism argument. The robotics/digitized economy trend will certainly play a large role in health care, particularly in managing the welfare of graying populations.

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[7] For example, see Daron Acemoglu, "Technical Change, Inequality and the Labor Market," *Journal of Economic Literature*, March 2002, 7–72.

[8] Kevin Kelly, "Better Than Human: Why Robots Will—and Must—Take Our Jobs," *Wired*, December 2012.

Techno-pessimism

In their highly influential book *Race Against the Machine*, Erik Brynjolfsson and Andrew McAfee outline a future where technology destroys an array of jobs, particularly low-skill service and manual labor jobs.[9] They point out that technology will upgrade some jobs, but their assessment nets out with growing income inequality and suggestions of a need to devise new income redistribution, as wealth concentrates among the technology owners. While such a social course may have a logic of fairness, redistributing wealth tends to be an explosive political issue, more so in some nations than others.

Some prominent economists are among the ranks of techno-pessimists, arguing that the role of technology is overstated, and that innovation is diminishing in advanced industrial societies. Tyler Cowen of George Mason University makes the case in his book *The Great Stagnation* that the U.S. economy has plucked all the "low-hanging fruit" and that future economic growth and innovation will be low for a protracted period.[10] In a widely debated paper, "Is U.S. Growth Over?", economist Robert J. Gordon argues:

In setting out the case for pessimism, I have been accused by some of a failure of imagination. New inventions always introduce new modes of growth, and history provides many examples of doubters who questioned future benefits. But I am not forecasting an end to innovation, just a decline in the usefulness of future inventions in comparison with the great inventions of the past. Even if we assume that innovation produces a cornucopia of wonders beyond my expectations, the economy still faces formidable headwinds.[11]

Such pessimism should be taken with a grain of salt, occurring at a historical moment when the U.S. has suffered the worst economic crisis since the 1930s, a protracted recession amid anemic Western economic performance. Similar to many predictions of peak oil over the past 50 years and laments about imminent American decline, such doom and gloom may be unwarranted.

In a thoughtful discussion of the impact of robotics that assesses the techno-optimism and techno-pessimism arguments and suggests a third scenario, social scientist Richard Florida argues that human beings are not passive objects, and economic transformations are what societies make of them. "Our key tasks during economic and social transformations," Florida says, "are to build new institutions and new social structures and to create and put into effect public policies that leverage technology to improve our jobs, strengthen our economy and society and generate broad shared prosperity."[12] Florida concludes that the economy of the future is the "creative economy" because creativity has become "the fundamental factor of production." He argues that cities, rather than factories or large corporations, are "the key organizing unit of the postindustrial economy. . .[the] pivot point for creativity, the great containers and connecters."

The Dark Side of Robotics

A growing body of literature is exploring the many real and potential downside risks and ethical and social implications of robotics apart from displacing human labor.[13] Popular culture is filled with technophobic,

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[9] Brynjolfsson and Mcaffee, *Race Against The Machine*. . . .

[10] Tyler Cowen, *The Great Stagnation*, a Penguin Group eSpecial, Amazon, 2011 .

[11] Robert J. Gordon, "Is U.S. Economic Growth Over?," Centre For Economic Policy Research, Policy Insight No. 63, September 2012, summary in Robert J. Gordon, "Why Innovation Won't Save Us," *Wall Street Journal*, December 21, 2012.

[12] See Richard Florida, "Robots Aren't the Problem: It's Us," *The Chronicle of Higher Education*, March 25, 2013.

[13] See, for example, Patrick Lin, K. Abney, and G. Bekey, eds., *Robot Ethics: The Ethical and Social Implications of Robotics* (Cambridge: MIT Press, 2012).

demonic imagery of robots, from the movies *Blade Runner* and *Terminator* to *AI* and *I, Robot*. The rise of the use of military drones has sparked intense debate about the morality of war by remote control, and one can anticipate similar debates on automated warfare when robots become infantry soldiers.[14] Will smart robots make their own battlefield decisions? Could police robots have advanced enough AI to know whether an object pointed at them is a real gun or a water pistol?

A host of questions exist regarding efficacy and liability. However smart a machine may be, machines malfunction. Dependency on automated systems independent of human judgment and real-time monitoring, whether electric grids or robot cars, could pose risks and dangers. Given that AI is about software, what risk do hackers pose? Could cyber thieves hack Google-type driverless cars and steal them or wreak havoc on traffic? If a robot surgeon errs, who will be liable? Even if robots are programmed to obey laws and norms, what about cultural differences: whose laws and whose norms? How would the very nature of warfare change if some states used primarily robot soldiers and drones, removing the human risk factor from warfare, while other nations lacked such capability? If military conflict were removed from human impact, would that make conflict more or less likely? Would such automated warfare, so removed from any personal impact (e.g., friends and relatives dead or wounded), change the way citizens judge the necessity of particular wars and dilute a level of government accountability?

In addition, unanticipated social impacts may arise from the use of robots. In the area of health care, for example, would dependency on robots mean a decline in surgeons' or other medical employees' skills? Similarly, would increased use of robots and a decline in human interaction in education alter the learning process in negative ways? Psychological and emotional issues arise too from the use of robot caregivers to handicapped and elderly. Would the ill and elderly, who tend to be socially marginalized, suffer from a lack of human interaction? Or would they develop affinities for robot caregivers?

Conclusion

Robotics will be an important part of the social and economic landscape of the future. The pace and scope of deployment of robotics and the other components of the Third Industrial Revolution will largely be driven by the private sector. But the economic, social, political, and strategic consequences of the transformation will ripple through governments at every level.

Yet, there is dearth of planning or even due diligence by governments to develop an understanding of how emerging technologies such as robotics will change the way we work and live. Instead, a large gap tends to exist between the scientific and technological community and the government making and implementing economic, urban, and foreign policies. The imperative for governments around the world, working with their respective private sectors, is to begin to think through consequences of the imminent robotics explosion and fast approaching technology revolution and to prepare for, take advantage of, and mitigate the downside risk of these developments.

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[14] See Jane Mayer, "The Predator War," *The New Yorker*, October 26, 2009, for a sampling of an increasingly heated debate.

Technology Foresight, Social Equity, and International Stability

by Richard Silberglitt[1]

This chapter discusses the potential for technology development to contribute to solving global problems on the one hand and enabling dangerous and potentially harmful applications on the other. We propose a global technology commons for the former case, and global cooperation and agreements to support continued latency for the latter.

Forecasting versus Foresight

Forecasts predicting general trends that are likely to occur under specific conditions are extremely useful. For example, the U.S. Energy Information Administration (EIA) publishes an *Annual Energy Outlook*,[2] in which, in its Reference Case, it forecasts energy use, supply mix, and other important features of energy supply, demand, conversion, and utilization based on extrapolation of current trends and a combination of econometric and engineering models. These energy forecasts provide important input to government and businesses by predicting what will happen if the U.S. follows current trends. Through their "sensitivity cases," they also allow analysis of the effects of major uncertainties in areas such as world energy prices and technology developments.

Uncertainty is the principal nemesis of forecasts; as conditions change, extrapolations become problematic and predictions less certain.[3] In such situations, "foresight," the systematic investigation of a range of plausible future developments, is a useful approach that can allow consideration of the effect of a broad spectrum of events, trends, and actions without attempting to predict a single, most likely, outcome. Foresight, the topic of this chapter, can be a vehicle for expanding the range of future visions and then for considering which policy or other actions taken now can move a locality, country, region, or the world toward a desirable future.[4]

Foresight methods have been used for many years by countries around the world to inform science and technology (S&T) policy. Perhaps the oldest recurring national foresight is that performed by Japan's National Institute of Science and Technology Policy (NISTEP), which provides input on S&T developments to support decision-making for Japan's Science and Technology Basic Plan. The document also allows for evaluation of alternative S&T policies aimed at addressing social issues of importance to Japan, such as its declining birthrate and aging population, and global warming.[5] In its recent 9th Science

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[1] The statements and opinions expressed in this chapter are solely those of the author, and not of the RAND Corporation, and the author is solely responsible for its content. The author is extremely grateful to Philip Antón for his significant contributions to the global scenarios in Table 1, to Christopher Chivvis and Seth Jones for extremely helpful discussions of the connection between development and conflict, and to Steven Berner for continuing insightful dialog on the issues discussed in this chapter.

[2] "Annual Energy Outlook 2014," U.S. Energy Information Administration, is available at http://www.eia.gov/forecasts/aeo/, accessed February 18, 2014.

[3] One way to address this problem is by defining a "cone of uncertainty." See Paul Saffo, "Six Rules for Effective Forecasting," *Harvard Business Review*, July/August 2007, http://www.usc.edu/schools/annenberg/asc/projects/wkc/pdf/200912digitalleadership_saffo.pdf, accessed February 18, 2014.

[4] See, for example, *foresight, the journal of future studies, strategic thinking and policy,* http://www.emeraldinsight.com/products/journals/journals.htm?id=fs, accessed February 18, 2014; and Luke Georghiou, Jennifer Cassingena Harper, Michael Keenan, Ian Miles, and Rafael Popper, eds., *The Handbook of Technology Foresight* (Cheltenham, U.K.: Edward Elgar, 2008).

[5] See the NISTEP Director General's message at http://www.nistep.go.jp/en/?page_id=15, accessed February 18, 2014.

and Technology Foresight, NISTEP integrated the results of a Delphi survey that posited important developments in S&T over the next 15 years with a set of scenarios concerning how such developments might affect people's lives. The report also included a study of local capabilities for sustainable development in various regions of Japan.[6] The result was an integrated assessment of S&T scenarios for Japanese society that helped guide future national policies.

The Korea Institute of S&T Evaluation and Planning, through its Technology Foresight Center, recently described visions of four future worlds in around 2040 based on developments of 25 key technologies: (1) an "Eco-Friendly World" focused on clean energy, minimizing waste, and understanding the earth's environment, including, the Korean peninsula's climate; (2) an "Abundant World" based on advanced robotics to address a shrinking workforce, a second green revolution leading to Korean food self-sufficiency, and highly efficient, environmentally friendly materials; (3) a "Healthy World" resulting from advances in biotechnology, technologies to combat emerging diseases, and state-of-the-art security systems to ensure national and public safety; and (4) a "Convenient World" with coexistence of humans and robots, real and virtual worlds, and connection of all objects and spaces through embedded ubiquitous sensors and communication networks. These visions include roadmaps for the development of key technologies between the present and 2040.[7] Using foresight, the South Korean government sought a glimpse of the future and ways to accommodate it.

The U.K.'s Foresight program,[8] within the U.K. Office of Science, has published "in-depth studies looking at major issues 20–80 years in the future" in areas such as climate change, food and farming, sustainable energy, infectious diseases, and cyber-crime prevention. The program also operates a Horizon Scanning Center that conducts "short projects looking at more discrete issues 10–15 years in the future." Other European governments and nongovernmental organizations (NGOs) are active in foresight as well. A wide variety of foresight studies, including those reported from other parts of the world, are summarized on the European Foresight Platform (formerly the European Foresight Network [EFMN]).[9] Many different methods (e.g., literature reviews, scenarios, expert panels, futures workshops) were used separately and in combination to complete these foresight projects, as described in a review and analysis of 886 studies reported to EFMN and a sister organization, the Euro-Latin Foresight Network, also known as SELF-RULE.[10]

The Asia-Pacific Economic Cooperation (APEC) Center for Technology Foresight (CTF) was founded in 1998 within the National Science and Technology Development Agency of Thailand as a project of APEC's Industrial Science and Technology Working Group. With core funding from the Thai government, and collaboration with foresight projects involving multiple APEC economies, APEC CTF performs regional, sectoral, organizational, and APEC-wide foresights, and provides training in foresight methods aimed at developing and diffusing foresight capabilities. APEC CTF's foresight projects have

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[6] *Contribution of Science and Technology to Future Society*, NISTEP Report No. 145, Science and Technology Foresight Center, National Institute of Science and Technology Policy, December 2010, http://www.nistep.go.jp/achiev/ftx/eng/rep145e/pdf/rep145e.pdf, accessed February 18, 2014.

[7] "Science and Technology Vision for the Future: Toward the Year 2040," Korea Institute of S&T Evaluation and Planning, Seoul, Korea, 2011.

[8] See http://www.bis.gov.uk/foresight, accessed February 18, 2014.

[9] See http://www.foresight-platform.eu/, accessed February 18, 2014.

[10] Rafael Popper, "How are foresight methods selected?," *foresight*, **10**(6), 2008, 62–89. A brief describing SELF-RULE can be found at http://ec.europa.eu/europeaid/where/latin-america/regional-cooperation/alfa/documents/self-rule.pdf, accessed February 18, 2014.

addressed a range of problems and issues important to the Asia-Pacific region, including future fuels, megacities, water supply and management, sustainable transport, emerging infectious diseases, and low-carbon futures.[11] Foresight methodologies are widespread and increasingly vital to national and regional efforts to plan for S&T developments.

Foresight in the Local Context

Foresight methods such as those described in the previous section are also used within a local context by individuals and organizations. The "local context" here is not limited to geography but also includes a variety of specific social, economic, political, and cultural environments preparing to face future challenges. Foresight methods can provide perspective into adverse trends as well as pose possible solutions tailored to the particular needs of a community, interest group, or population. They can also identify drivers and barriers to proposed solutions and project-required capacity (e.g., human capital, physical infrastructure, and government and institutional systems) needed to implement policy preferences. The goals of policy can be as expansive as improving the human condition, such as the United Nations Millennium Development Goals,[12] or they may seek pathways to acquire specific technological, economic, or military capabilities. As with all technology, foresight is a tool to achieve human-conceived ends that naturally reflect the dual capacity of humans to improve the world or do it harm. The topic of this book, strategic latency, is concerned with preventing technologies from being implemented along the harmful track. In this chapter, I suggest using foresight methods to inform policies to promote constructive applications of technologies for human betterment while minimizing latent harmful applications.[13]

It is possible to use foresight to advance the cause of social equity through economic development that empowers disadvantaged citizens or groups. The *State of the Future* studies published annually by The Millennium Project,[14] an independent nonprofit organization, provide a good example. These studies track progress toward 15 global challenges, including the rich–poor gap, the status of women, sustainable development, democratization, clean water, population, and resources. They show where the world is improving and where it is not, and produce a State of the Future Index that allows explicit comparison of the development record of different countries with respect to the world median.[15]

Building on the foresight studies performed by the Millennium Project and APEC CTF, among others, a 2009 article in *foresight* lays out a path and makes policy recommendations for the use of science, technology, and innovation to reduce poverty and improve the quality of life in specific developing

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[11] A description of the mission, history, and activities of the APEC Center for Technology Foresight, as well as access to its publications, can be found at www.apecforesight.org, accessed August 19, 2011.

[12] The U.N.'s Millennium Development Goals are a set of targets aimed at reducing extreme poverty with a stated deadline of 2015 that were adopted by world leaders at the Millennium Summit in September 2000. The U.N. releases periodic assessments of progress toward achieving these goals. See *The Millennium Development Goals Report 2013* (New York: United Nations, 2013), http://www.un.org/millenniumgoals/pdf/report-2013/mdg-report-2013-english.pdf, accessed February 19, 2014.

[13] Richard Rhodes, *Visions of Technology* (New York: Simon and Schuster, 1999), provides an anthology of readings on both projected and observed positive and negative effects of technology on society. On p. 268, we find the following quote that is particularly relevant to this book: "Technology has *two* faces: one that is full of promise, and one that can discourage and defeat us. The freedom that our power implies from the traditional tyranny of matter—from the evil we have known—carries with it the added responsibility and burden of learning to deal with matter and to blunt the evil." (Emmanuel G. Mesthene, 1967)

[14] A description of the mission, history, and activities of The Millennium Project, as well as access to its publications, can be found at www.millennium-project.org, accessed February 18, 2014.

[15] See Jerome C. Glenn, Theodore J. Gordon, and Elizabeth Florescu, "2012 State of the Future," The Millennium Project, 2011. The Executive Summary is available at http://www.millennium-project.org/millennium/2012SOF.html, accessed February 14, 2014.

countries.[16] In fact, as described a decade earlier by Professor Freeman Dyson,[17] a long historical record of emerging technologies has enabled the empowerment of economically disadvantaged people and thus promoted social justice, including the printing press, water supply, sewage treatment, vaccinations, antibiotics, synthetic materials, and household appliances. Professor Dyson presents a future vision in which the combination of cheap solar energy, industrial biotechnology, and widely available Internet access promote social equity throughout the world. This chapter explores how working toward this vision can enhance local economic and social stability in the developing world and enable a future that promotes international action to prevent the development and implementation of dangerous or harmful technology applications.

Foresight and Local Stability

Analysis of data on civil wars provides ample evidence of the link between poverty and instability. For example, in the post-Cold War era, insurgencies have been driven more by poverty in financially and bureaucratically weak states than by ethnic and religious diversity.[18] Moreover, the risk of conflict was observed to be much higher in countries with a specific set of economic characteristics: (1) low per capita income, (2) negative economic growth, and (3) dependence on natural resource exports.[19]

Furthermore, an extensive analysis of data on all civil wars since 1945 led to the conclusion that three key factors determine the difficulty of resolving such conflicts: (1) the degree of hostility of the conflict, (2) the extent of local capacity, and (3) the amount of international assistance (political, military, economic, and other). Here, local capacity is measured either by per capita gross domestic product or by per capita electricity consumption, both of which are indicators of economic development. The analysis indicates that peace building requires security, institutions for conflict resolution, and an economy that can provide employment for former soldiers and material progress for citizens. Moreover, it concludes that low levels of per capita income significantly exacerbate risks of civil war.[20]

While these analyses strongly correlate economic development to stability, a hierarchy of tasks must also be accomplished to move a post-conflict society into a situation in which it can enjoy domestic stability as well as peace with its neighbors.[21] These tasks are: (1) security, (2) humanitarian relief, (3) governance, (4) economic stabilization, (5) democratization, and (6) development. While they do not necessarily have to be pursued sequentially, investments in tasks at the lower end of this hierarchy, such as development, will likely not bear fruit unless certain higher-order tasks are pursued first. For example, to successfully accomplish economic development, one must first establish security, provide basic human needs such as food and shelter, and establish public services and economic and civil institutions.

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[16] Nares Damrongchai and Evan S. Michelson, "The Future of Science and Technology and Pro-Poor Applications," *foresight*, **11**(4), 2009, 51–65.

[17] Freeman J. Dyson, *The Sun, The Genome, and The Internet* (New York: Oxford University Press, 1999), 50–53.

[18] James D. Fearon and David D. Laitin, "Ethnicity, Insurgency, and Civil War," *American Political Science Review*, **97**(1), February 2003, 75–90.

[19] Paul Collier and Anke Hoeffler, "The Challenge of Reducing the Global Incidence of Civil War," Copenhagen Consensus Challenge Paper, April 2004, http://www.copenhagenconsensus.com/sites/default/files/CP%2B-%2BConflicts%2BFINISHED.pdf, accessed February 18, 2014.

[20] Michael W. Doyle and Nicholas Sambanis, *Making War and Building Peace: United Nations Peace Operations*, (Princeton, N.J.: Princeton University Press, 2006).

[21] James Dobbins, Seth G. Jones, Keith Crane, and Beth Cole DeGrasse, "The Beginner's Guide to Nation-Building," RAND Corporation, MG-557-SRF, 2007, www.rand.org/pubs/monographs/MG557, accessed February 18, 2014.

The application of emerging technologies can support these higher-order tasks. For example, technology applications such as mobile, networked communications and tracking of resources using radio frequency identification tags can contribute to the success of security forces, ensure that humanitarian supplies reach intended targets, and strengthen developing institutions. However, the analyses described above suggest that it might be even more productive to apply emerging technologies *before conflict occurs* to achieve the type of broadly based economic development that can remove the seeds of such conflict. Next, then, I explore a range of technology development scenarios, including some that promote stability, and some that promote instability, as well as the development of potentially harmful latent capabilities.

Scenarios of Technology and Stability

Many possible futures are enabled by the development or acquisition and subsequent implementation of technology applications, some promoting stability and some with potentially dangerous outcomes. The field of nanotechnology alone provides a host of examples with both positive and negative implications. Positive examples include nanoscale formulations of therapeutic drugs and nanoscale vehicles for targeted diagnostics and drug delivery.[22] Such developments could potentially lead to inexpensive and widely available diagnostics and therapies available for those in need regardless of their economic or social status.[23] However, as noted previously, technology has two faces. In the case of nanotechnology, it can also enable small and autonomous devices that may be invisible under certain conditions and could be used for tracking and invasion of privacy.[24] Other applications of technology with potentially negative impacts on local and global stability include sensor networks that could be used to penetrate defenses and enable delivery of chemical, biological, or radiological agents to heavily populated areas, perhaps using simple delivery methods.[25]

For the purpose of the current discussion, we define three fundamental categories of technology applications: (1) those that can enable the solution of global problems such as poverty, hunger, and disease, (2) those that can do great harm, in some cases by enabling capabilities that so far have been latent, and (3) those that fall clearly into neither of these two categories. We realize that such categorization must be a dynamic process, because developments in S&T may provide the potential for new applications

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[22] See, for example, *Nanotechnology at NIH: Basic Concepts, Current Research, and Medical Applications*, videocast available at http://www.nih.gov/science/nanotechnology/, accessed February 18, 2014, and Simona Mura, et al., "Stimuli-Responsive Nanocarriers for Drug Delivery," *Nature Materials*, **12**(11), 991–1003.

[23] The requirements and potential benefits are described in *Determining the Global Health Impact of Improved Diagnostic Technologies for the Developing World*, Supplement to Nature Publishing Group, *Nature*, S1, http://www.nature.com/diagnostics, accessed February 18, 2014.

[24] The burgeoning field of metamaterials that enables such "cloaking" also presents a microcosm of positive and negative possibilities, from improvements in telecommunications and biological labeling to covert tagging and the potential for deception to mask disruptive activities. See the reviews, Huanyang Chen, C. T. Chan, and Ping Sheng, "Transformation Optics and Metamaterials," *Nature Materials*, **9**(5), 387–396; A. V. Kildishev and V. M. Shalaev, "Transformation Optics and Metamaterials," *Physics-Uspekhi*, **54**(1), 53–63, http://iopscience.iop.org/1063-7869/54/1/R05, accessed February 18, 2014; and O. Hess, et al., "Active Nanoplasmonic Metamaterials," *Nature Materials*, **11**(7), 573–584.

[25] Many small and remotely controllable platforms are readily available, and the capability to design and construct them is growing. For some examples of commercial applications, see Richard Conniff, "Ready for Takeoff," *Smithsonian*, June 2011, 42–49. For a report on the demonstration of "swarm" behavior, see Debra Werner, "Drone Swarm: Networks of Small UAVs Offer Big Capabilities," DefenseNews, June 12, 2013, http://www.defensenews.com/article/20130612/C4ISR/306120029/Drone-Swarm-Networks-Small-UAVs-Offer-Big-Capabilities, accessed February 18, 2014. For a description of available technology from one vendor that recognizes "Government Regulations Regarding the Restricted Export of UAVs fitted with Navigation Avionics," see http://www.silvertone.com.au/uav2.pdf, accessed February 18, 2014.

of emerging or existing technologies that move them between categories. For example, the growth of do-it-yourself biotechnology laboratories was inspired by a desire to increase the rate of innovation for mostly altruistic reasons, but such laboratories could allow the development and/or release of harmful pathogens.

The ability of countries around the world to take advantage of emerging technologies to address the problems and issues most important in their local context is highly variable.[26] Moreover, as noted in the discussion of economic development and stability above, the institutions to identify and implement such technologies are often lacking in developing countries. These factors therefore suggest the need for a global technology commons for applications that fall into the first category above. Such technology applications should be made available on a global basis to populations in need, to provide solutions to local health, education, and infrastructure problems, enabling the type of economic development that would provide material progress to promote local stability. Technology applications that would come under the purview of a global commons include water purification and vaccines, as well as energy and wireless communications for rural areas. Several organizations and agencies are pursuing initiatives consistent with this proposal.[27] In the context of this book, we propose extending the approach of the Nuclear Non-Proliferation Treaty to other technologies with harmful latent applications of potentially strategic importance. Following this line of thought, the global technology commons would be coupled to a set of global control agreements for technology applications that fall into the second category defined above, such as those currently in place for weapons of mass destruction.[28]

The global technology commons and its associated web of agreements to prevent the diversion of potentially destabilizing latent technology would encourage global stability. Consider the possible drivers of such a future. At the end of the 20th century, Allen Hammond[29] contrasted two possible futures, a "Market World," in which the Davos vision of economic growth through market forces solves the world's problems, and a "Fortress World" in which markets cannot cope with global problems, and barriers between have and have-not populations continue to grow higher. Not willing to embrace the failure of markets and the consequent global slide into a fortress mentality, Hammond suggested an alternative, a "Transformed World," driven by the global activism of NGOs dedicated to a future in which political stability and social equity are the top priority. Hammond's vision is not unlike that of Freeman Dyson, discussed earlier, in which NGOs control technology and bypass self-interested national governments to achieve global economic and humanitarian goals. Such a global technology commons circumvents "realist" concepts of international politics and lays the groundwork for a new international order.

How might technology impact the evolution of the world along one or more of these tracks? To explore this question, consider the following drivers of country, regional, and nongovernmental decision-making:

- Economic power and global markets.

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[26] See, for example, Richard Silberglitt, Philip S. Antón, David R. Howell, and Anny Wong, "The Global Technology Revolution 2020: Bio/Nano/Materials/Information Technology Trends, Drivers, Barriers, and Social Implications," RAND Corporation, Santa Monica, CA, MG-475-NIC (Executive Summary), http://www.rand.org/pubs/monographs/MG475, accessed February 18, 2014, and TR-303-NIC (In-Depth Analyses), http://www.rand.org/pubs/technical_reports/TR303, accessed February 18, 2014.

[27] See, for example, the Social, Technological and Environmental Pathways to Sustainability (STEPS) centre at the University of Sussex, U.K., http://www.steps-centre.org/, accessed February 18, 2014; and Allen L. Hammond, et al., "The Next 4 Billion: Market Size and Business Strategy at the Base of the Pyramid," International Finance Corporation, World Bank Group and World Resources Institute, undated, Executive Summary available at http://pdf.wri.org/n4b_executive_summary_graphics.pdf, accessed February 18, 2014.

[28] See Zachary S. Davis, "Strategic Latency and World Order," *Orbis*, Winter 2011, 69–84.

[29] Allen Hammond, *Which World? Scenarios for the 21st Century* (Washington, D.C.: Island Press, 1998).

- Governance and social structure.
- Culture and religion.
- Military power and weapons.
- Demographics.
- Natural resources and infrastructure.

We then consider alternative scenarios in which the combined effect of these drivers moves the world toward greater or lesser levels of stability. We call the former, characterized by cooperation between countries and NGOs, "Linked World." We call the latter, characterized by little global cooperation and much opportunistic behavior, "Chaos World." We call today's situation "Hybrid World," because examples of both types of behavior are evident. The table below summarizes these scenarios and their major variables.

Alternative Global Scenarios

	Linked World	Hybrid World (current state)	Chaos World
Country Stability	More stable	Mixed	Dynamically stable and unstable
Economics	Market linkages and global agreements	Large differences: 1st and 3rd worlds	Large differences: opportunistic
Military Power	Used to enforce global agreements	Allies, local and regional powers	Constantly changing relationships
Quality of Life and Environment	Improvements dependent on local context	Differences dependent on local context	Very large differences
Nationalism and Culture	Subservient to linkages and peace	Some subservient and some strong	Strong driver of behavior

The reason for the categorization of technology applications above is now clear. Technology applications in the second category, in the absence of global controls, enable opportunistic behavior that degrades international diplomacy and trust, causing movement toward a Chaos World. On the other hand, technology applications in the first category, through a global technology commons, can improve social equity and develop trust between countries and NGOs, causing movement toward a Linked World. Which direction the world evolves will depend upon how well international cooperation and technology governance work to provide stability in parts of the world that are, or could soon be, in conflict, thus supporting the continued latency of dangerous technology applications.

Technology Development Paths

We have shown how foresight can elucidate technological approaches to address important problems and issues within the local context of countries, regions, groups, or individuals. We have also identified the capacities that need to be developed to achieve goals and objectives. We have also explored the different paths that technology development can take, with different outcomes:

- Promotion of stability through economic development that contributes to productive employment, social equity, and improved quality of life, or

- Promotion of conflict through the development of capabilities that can be used by individuals, groups, or nations for nefarious purposes, and that would otherwise remain latent.

Which path development takes will be dependent upon the goals and objectives of individuals, groups, and nations, as well as the global policies and governance to which they agree and submit. The potential for global governance to address the control of dangerous latent capabilities is discussed in the following chapter.

3D Printing: More Opportunities Than Dangers

by Banning Garret[1]

3D Printing . . . has the potential to revolutionize the way we make almost everything. —President Barack Obama, State of the Union, February 12, 2013

The future is already here—it's just not very evenly distributed. —William Gibson, Fresh Air, August 31, 1993

President Obama is right. 3D Printing (3DP, more formally known as additive manufacturing[2]) is a revolutionary technology that has the potential to revolutionize the way we make almost everything. In the process, 3DP is likely to up-end the last two centuries of design and manufacturing with profound geopolitical, economic, social, demographic, environmental, and national security implications that will unfold over the coming two decades and beyond.

The *Economist* has hailed 3DP as the basis of a "third industrial revolution."[3] This new industrial revolution is likely to dramatically change business models, shift production locations, shrink supply chains, and alter the global economic order, potentially degrading the importance of the Asian manufacturing platform and revitalizing the U.S. innovation engine and the U.S. economy. In the process, 3DP will change the "global operating environment" for policy makers and will transform operations for the military, from printing spare parts and food to redesigning weapons and military equipment and the business model for purchasing and maintaining those systems.[4]

While 3DP has enormous potential to transform the world of the future, 3DP is already here. It is a proven general purpose technology being used for an enormous range of purposes, such as fabricating spare and new parts for planes, trains and automobiles and thousands of items in between.[5] Future applications that are under development range from printing human organs and food to printing airplane wings and large structures, including houses and large buildings and bases on the moon and Mars. NASA views 3DP as an essential part of its space exploration plans, with 3D printers replicating themselves and

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[1] This article is based in part on "Could 3DP Printing Change the World? Technologies, Potential and Implications of Additive Manufacturing," written by the author with Thomas Campbell, Christopher Williams and Olga Ivanova of Virginia Tech, Atlantic Council, October 2011, http://www.acus.org/files/publication_pdfs/403/101711_ACUS_ACU.S._3DPrinting.PDF.

The author gratefully acknowledges review of this article by Dr. Thomas A. Campbell, associate director for outreach, and research associate professor, at the Institute for Critical Technology and Applied Science (ICTAS), Virginia Tech, http://ictas.vt.edu.

[2] 3D printing is also known as additive manufacturing (AM), which is a more generic term denoting the opposite of "subtractive manufacturing." Because 3D printing has become the most widely used term in the media for the 3D printing process, this paper uses the terms 3D printing (3DP) instead of additive manufacturing. There are other manufacturing processes—such as stamping, casting, and injection molding—that are not subtractive but are for mass production of identical products made from one material such as plastic for toys or steel for bolts.

[3] "Special Report: Manufacturing and Innovation," *The Economist*, April 21, 2012.

[4] See *Global Trends 2030: Alternative Worlds*, National Intelligence Council, December 2012, 90–93, which discusses the current and potential implications of 3D printing, although some of the developments it foresees as possible by 2030 are likely to be available in the next few years. The document is available at http://www.atlanticcouncil.org/publications/reports/global-trends-2030-alternative-worlds. .

[5] Conceptually, 3DP has existed since the time of raised relief maps, in which 3D terrain is approximated by stacking 2D layers. 3DP technology first emerged in 1977, when Swainson suggested a method of creating 3D objects directly by using two electromagnetic radiation beams and a sensitive polymer that solidifies in the presence of the beam. This method is considered to be the ancestor of modern stereolithography. Over the past four decades, 3DP techniques have further evolved. Researchers in the domains of mechanical engineering and materials science have focused on improving old and creating new techniques, as well as developing novel materials.

making spare parts as well as large structures in space.[6] And, of course, 3DP has recently attracted the attention of Congress and the public with reports that people have printed guns and high-capacity magazines for assault weapons.[7]

3DP machines vary widely in size, resolution, materials used, cost, and applications. Moreover, 3DP affects different economic and manufacturing sectors in different ways and at different rates. Overall, 3DP is a classic disruptive technology[8] that is likey to have a huge and widespread impact on the world. While some skeptics maintain that 3DP is overhyped, GE's CEO Jeffrey Immelt commented at a February 2013 conference in Washington that 3DP is "worth my time, attention, money, and effort."[9] It is not too risky to project the continued growth in the manufacturing revolution that has been sparked by 3DP. Because 3DP has many inherent advantages over other manufacturing technologies, any other technology that could theoretically replace 3DP would likely go in the same disruptive direction and just do the job better and cheaper.

3DP's "strategic latency" is already apparent with even greater potential implications as the technology becomes more mature and widely used in more varied applications. For policy makers, 3DP is transforming their world and promises to have a far greater impact in the future, posing dangers, opportunities, and overall a changing foreign policy and national security landscape. This technology is also being developed in an era in which governments do not control and are often not the key innovators in many new critical technologies. As Zachary Davis notes in his introductory essay to this volume, "countries no longer control research and development of cutting edge technologies, the most consequential of which (such as nuclear weapons) used to be 'born secret' and remain controlled from cradle to grave." In this new era, according to Davis, "potentially world-changing technologies in biology, lasers, nanotech, space and computers are essentially ungoverned."

While nuclear weapons may be the "poster child" for the past era of government-controlled technology development, 3DP is the poster child for a new, strategically important technology that is not only out of the control of governments but is being rapidly developed from the "bottom up" by tens of thousands of do-it-yourself (DIY) hobbyists as well as from the "top down" by businesses, universities, and government-sponsored research institutions. The 3DP genie is already out of the bottle. The challenge for the U.S. and other countries is to capitalize on the huge potential economic, environmental, and social benefits of this technology while hedging against potential security risks created by the new capabilities the technology is rapidly generating.

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[6] Dina Spector, "In The Future, Astronauts Could Print Out Their Moon Bases," *Business Insider*, February 4, 2013, http://www.businessinsider.com/3d-printed-moon-base-2013-2.

[7] See, for example, Michael. S. Rosenwald, "Weapons Made with 3D Printers Could Test Gun-Control Efforts," *Washington Post*, February 20, 2013, http://www.washingtonpost.com/local/weapons-made-with-3-d-printers-could-test-gun-control-efforts/2013/02/18/9ad8b45e-779b-11e2-95e4-6148e45d7adb_story.html.

[8] Noted in an excellent analysis of the impact of 3DP, "3D Printing and the Future of Manufacturing," CSC Leadingedge Forum Technology Program, Fall 2012, http://www.csc.com/lef/insights/92142-3d_printing_and_the_future_of_manufacturing.

[9] "Is 3D Printing Overrated? Not at All, Says GE's Jeffrey Immelt," *Theatlantic.com,* February 7, 2013, http://www.theatlantic.com/business/archive/2013/02/is-3d-printing-overrated-not-at-all-says-ges-jeffrey-immelt/272965/.

A Third Industrial Revolution?

3DP has been the focus of increasing attention with many articles and books explaining how it works.[10] What distinguishes 3DP from traditional manufacturing is that it builds products layer-by-layer—additively—rather than by subtracting material from a larger piece of material such as carving out a landing gear from a block of titanium—that is, "subtractive" manufacturing. The 3DP process begins when a designer creates a 3D computer representation of an object by using computer-aided design (CAD) software or by 3D scanning of an existing object. 3DP software then creates a file that "slices" the virtual object into cross-sectional layers. The resulting ".stl" file is sent to the 3D printer, which then builds the object from the bottom up, layer by layer. This process can be visualized by thinking of an inkjet printer which prints a layer of ink at designated points (for words or an image). But instead of the paper moving on and another page being printed, the paper drops down slightly on a platform and another layer of ink is printed on top. Instead of using ink, the 3D printer is adding layers of material such as plastic, ceramics, metal, human cells, etc., until the virtual object has become a fully constructed, 3D physical object. The seemingly small distinction that 3DP is layering or adding, rather than subtracting as in traditional manufacturing, embodies a revolution in designing and fabricating physical objects.[11]

3DP offers a number of structural benefits over traditional manufacturing:[12]

- *Increased Product Design Freedom*: Traditionally, products designs are constrained by the limitations of the machines that will produce them. An immediate benefit of 3DP is the ability to create complex shapes that cannot be produced by any other means. Fundamentally, the 3DP processes allow designers to selectively place material only where it is needed. Taking inspiration from nature (e.g., coral, wood, bone), designers can now create cellular materials–strong and stiff structures that are also lightweight.[13] The design freedom thus extends to the internal structure of a product. For example, curving internal cooling channels can be integrated into components of fighter aircraft as well as the honeycombed structure of reeds can be integrated into steel tubing.
- *No Cost for Complexity*: In traditional manufacturing, the more complicated a product, the more expensive it is to manufacture—if it is even possible to make it at all. In 3DP, "fabricating an ornate and complicated shape does not require more time, skill, or cost than printing a simple block."[14] In metal casting and injection molding, a new product requires a new mold in which to cast the part. In machining, several tool changes are needed to create the finished product. However, 3DP is a "single tool" process—no matter the desired geometry, there is no need to change any aspect of the process. This, in effect, makes shape complexity free—there is no additional cost or lead time between making an object complex or simple. As such, 3DP processes are excellent for creating customized, complex geometries. Moreover, products with interlocking parts such as gears can be produced in one process with no assembly required.

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[10] See Garrett, Campbell, Williams, and Ivanova, "Could 3D Printing Change the World?," for more extensive technical explanations.

[11] Two recent books on 3DP explore the new technology and its implications in great detail. See Chris Anderson, *Makers: The New Industrial Revolution* (New York: Crown Business Books, 2012), and Hod Lipson and Melba Kurman, *Fabricated: The New World of 3D Printing* (New York: John Wiley & Sons, 2013). See also Al Gore, *The Future: Six Drivers of Global Change* (New York: Random House, 2013), 30–33.

[12] See also "The Ten Principles of 3D Printing" in Lipson and Kurman's *Fabricated*, 20–24.

[13] For example, see the DREAMS Lab (www.dreams.me.vt.edu) of Virginia Tech.

[14] "Ten Principles of 3D Printing," in Lipson and Kurman's *Fabricated*, 20.

- *On-Demand Production in Batches of One:* A given 3DP manufacturing facility is capable of printing a huge range of types of products without retooling—and each print run can be customized without additional cost. Moreover, products can be printed on demand without the need to build up inventories of products and spare parts.
- *From Mass Production to Mass Customization:* Because printing one-of-a-kind products is no more costly than mass producing the same object, 3DP technology enables the design and efficient manufacture of personalized products. This unique capability of 3DP is driving a transition from mass production to mass customization, in which each item produced is customized for the user at little or no additional production cost.[15]
- *Simplification of Manufacturing Process*: Because 3DP creates physical products directly from a standardized digital file, these computer-controlled processes require a low level of operator expertise and reduce the amount of human interaction needed to create an object. In fact, the processes often operate unmonitored, allowing for overnight builds, dramatically decreasing the time to produce products, and thus reducing the time between design iterations. Furthermore, creating the product directly from the computer model ensures that the product precisely represents the designer's intent, which reduces inaccuracies often found in traditional manufacturing processes.
- *From Prototypes to Finished Products:* Initially, 3DP was referred to as "rapid prototyping" and was primarily used to quickly fabricate conceptual models of new products for form and fit evaluation. An architect could design a new building on a computer and print out a 3D model to show a client or further refine the design. An automotive engineer could design and print a prototype front fascia to a vehicle. As material properties and process repeatability improved, the use of 3DP technologies has evolved from solely creating prototypes to fabricating parts for functional testing, to creating tooling for injection molding and sand casting, and finally, to directly producing end-use parts.
- *Eliminating Supply Chains and Assembly Lines for Many Products:* The final product—or large pieces of a final product such as a car—can be produced by 3DP in one process, unlike conventional manufacturing in which hundreds or thousands of parts must be assembled. And those parts are often shipped from dozens of factories from around the world—factories that may have in turn assembled their parts from parts supplied by others. .
- *Designs, not Products, Move around the World*: A digital file can be sent to any printer anywhere that can manufacture the product within the design parameters of the file (i.e., that can print the size, resolution, and materials called for in the file.) The Internet first eliminated distance as a factor in moving information instantly across space. Just as a written document can be emailed as a .pdf and an identical copy printed in 2 dimensions, a 3DP .stl design file can be sent instantly to the other side of the planet via the Internet and printed as an identical 3D physical object. A digital file of bits can be rematerialized into a physical object composed of atoms.
- *Instant Production on a Global Scale:* The representation of physical artifacts with a digital file enables rapid global distribution of products, thus potentially transforming product distribution in much the same way the MP3 did for music.

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[15] While 3DP technologies offer critical advantages over traditional manufacturing processes, there are inherent limitations that keep these processes from being a panacea for every manufacturing problem. In their current embodiments, 3DP processes are limited for mass production purposes since the build rate is much slower than that of an injection molding machine that makes large numbers of identical, single material products. While 3DP processes will continue to increase in speed, it is unlikely they will ever be able create parts as fast as molding technologies. The bottleneck lies in the fundamental physics of the processes—it is not possible to scan a laser (and cure material and recoat each layer) at a speed comparable to that of injection molding. This limitation is only valid for the production of several thousand of a common part, however. Because tooling must be created for each unique part one wishes to injection mold, 3DP is the preferred process when custom parts, or low-volume production runs, are needed.

- *A Boost to Innovation*: The rise of 3DP will likely lead to the reinvention of many old products, as well as to extraordinary innovations. Since 3DP processes can print virtually anything that can be designed on a computer—thus eliminating the limitations posed by machine tools, stamping, and molding—engineers and designers will no longer be limited in their designs because of previous manufacturing technologies. Moreover, 3DP allows an engineer or designer to "print" her or his ideas immediately to assess the viability of the product and incorporate design changes. Instant incorporation of design modification and product improvement for each printing allows for the constant updating of products as well as customization of each produced item to meet the needs and specifications of the user. New hybrid materials, such as nanocomposites via 3DP, are being researched to take design and material properties manipulation even further.[16] These materials could lead to better products that competitors will not be able to match without also adopting the new design and manufacturing process, thus accelerating the pace of adoption of 3DP technology.
- *Stimulation of New Interest in Design and Engineering:* The direct relationship between the designer and the product—a relationship that has been strained by the past 200 years of industrial production methods—will be similar to the relationship between software engineers and their products. As a result, interest in engineering and industrial design could be spurred, as has happened in the field of computer science and software engineering over the last half century.

The World Transformed?

3DP is empowering the individual to become an all-in-one designer, manufacturer, and entrepreneur. This "democratization" of manufacturing is only in its nascent stage, but it is already challenging long-standing business models. In the past, even if one had a good idea, designing the product and testing it through prototyping could be prohibitively expensive for an individual or small group. Even if a commercially viable prototype could be produced, moving to actual commercial production required finding a manufacturer or the capital to set up your own manufacturing facility and hiring management and workers and perhaps off-shoring the process to China or another low-cost manufacturing platform. Finally, the inventor/entrepreneur had to establish supply chains for the manufacturing inputs and distribution systems and outlets for the final products. Thus, before any products were produced and sold commercially, perhaps millions or tens of millions of dollars and months if not years of effort were spent and huge risks taken. Failure could mean financial ruin.

With 3DP, the process is radically changed. The cost of entry is reduced by orders of magnitude. For $1,000–$2,000, an individual can buy a 3D printer and use a computer attached to the Internet to download free software to create a product designed from scratch using simple plastic polymers. (More expensive printers are required for metals and other materials.) The DIYer could also download preexisting, open-source 3DP designs available at many websites that can be printed as-is or modified, or simply use free software and a cheap scanner to scan an object in 3D and print the object. The individual "maker" can not only modify the prototypes but also print the object for commercial sale—and use the Internet to find customers anywhere in the world who want either the physical object itself or the design to print the object themselves.

This entire process bypasses the traditional manufacturer and reduces financial risk to near zero. The main cost is the time invested by the individual entrepreneur, who might even have a "day job" and thus not require commercial success of the manufacturing venture.

This low-cost, low-risk model echoes the software industry, where college dorm projects led to Yahoo!, Google, Facebook, and other wildly successful startups. In the past, finding success in manufacturing was

[16] For example, see the Laboratory for Engineered NanoSystems (LENS) of Virginia Tech, www.lens.ictas.vt.edu.

nearly impossible as the cost to entry was typically prohibitive. No longer. Now almost anyone, anywhere can get into the game of the world of atoms in the same way that the world of bits has been open to computer innovators. This democratization of design and production will unleash a new age of innovation across nearly every field of making physical objects. Unfortunately, this new process will also provide empowerment for individuals and groups who seek to harm others by making guns, drones, and other weapon systems. 3DP also reduces their dependence on supply chains of all kinds.[17]

Friend of the Earth: Reducing Waste and Emissions

3DP is likely to play a significant role in dramatically increasing the efficiency of raw materials use and reducing overall costs, energy consumption, the production of greenhouse gases, and toxic waste. 3DP processes are inherently "green" compared to subtractive manufacturing. Because material is added layer by layer, only the material needed for the part is used in production. There is nearly zero waste. The 3DP process contrasts starkly with conventional manufacturing processes in which as much as 90 percent of the raw metal is wasted.[18] 3DP will thus enable the output of far more product from a given amount of material, reducing the strain that the rapidly growing global middle class and overall population are putting on the world's finite natural resources. Waste will also be reduced by printing on demand rather than building up stocks of items. On-demand production eliminates the energy, warehousing, and other costs of storing unsold inventory and spare parts, many of which may end up in landfills.

Just-in-time production at the point of consumption will reduce energy consumption and carbon emissions because far less shipping will be required. Today, manufacturing requires bringing together hundreds of parts from dozens of suppliers to a factory where the final product is assembled. 3DP will require only shipments of raw materials inbound to the factory and of final products outbound.

3DP will reduce or eliminate the use of many toxic chemicals used in conventional manufacturing, which in turn reduces the difficulty and expense of toxic waste disposal. There are also new opportunities for recycling of materials for reuse with 3DP as well as increased use of local materials.

The trend toward increasing competition for resources and possible resource conflicts could be slowed or reversed. In addition, international efforts to address environmental challenges, especially climate change, could receive a boost as the cost of taking ameliorative or mitigating actions is reduced.

Bringing It All Back Home: Long-Term Shift in the Global Economy?

The widespread use of 3DP could significantly alter the structure of the global economy. Production and distribution of material products may begin to be deglobalized, with manufacturing taking place closer to the point of consumption. Manufacturing could be pulled away from "manufacturing platforms" such as China and brought back to the countries where the products are consumed. Localization of production could reduce global economic imbalances as export countries' surpluses are reduced and importing countries' reliance on imports shrink with a new form of "import substitution" taking hold.

This shift will reduce the movement of finished goods around the world. The decentralization of manufacturing to sites all over the globe also will reduce the needed quantitative output of any one facility, thus rendering less important the speed of manufacture. "Mass production" of hundreds of thousands of a given product may be accomplished by producing thousands of the same product on hundreds of printers

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[17] The maker revolution is explained in depth by Chris Anderson in *Makers, The New Industrial Revolution* (New York: Crown Publishing Group, 2012). See especially Chapter 1, "The New Industrial Revolution."

[18] "Ten Principles of 3D Printing," in Lipson and Kurman's *Fabricated*, 22. The authors also note, however, that studies show that 3DP can be less environmentally friendly than injection molding for plastic parts made in large numbers, *Fabricated,* 202–203.

that are near the source of demand rather than producing all at one factory. This process could serve to bring supply and demand into near-perfect alignment as the products are printed where and when there is specific demand. Printing on demand without the need to build up inventories of products will reduce costs for both the maker and the end user.

Moreover, the same printers producing smaller numbers of identical items can be quickly reprogrammed to produce different products to meet new demand. The range of products that can be produced by a traditional assembly-line factory is extremely limited compared with the capability of a local 3DP facility.

The ability to print spare parts will have significant implications for businesses, the military, and consumers. Manufacturers could print spare parts from their stored computer files as needed rather than maintain huge stores. 3DP is already playing an increasingly important role in manufacturing spare parts for the U.S. military, especially on ships and at forward bases, reducing repair time and cost. As the use of 3DP expands, the need to maintain large inventories of spare parts will decline and the long delays, sometimes extending to many months, often involved in acquiring spare parts, will be eliminated. The Defense Advanced Research Projects Agency (DARPA) is working on printing technologies, especially for spare parts.[19]

Consumers could also benefit from 3D printers at local facilities or even at home to manufacture spare parts for household items. Software designs could be downloaded from the manufacturer, or the original part could be scanned to print an identical replacement.

3DP will create new industries and professions. Production of printers of all kinds and levels of sophistication is already a rapidly expanding industry, with a growing customer base from industrial and individual users to new manufacturing centers, printers in local stores, and government agencies.[20] The shift in global manufacturing to 3DP processes could involve trillions of dollars in business over the coming decades, including the value of products produced, and the cost of the printers themselves and professional services for product engineering and design. The production and distribution of printer cartridges with a wide variety of materials is likely to be an especially profitable industry, as it has been in the 2D printing world for Hewlett-Packard and other printer makers. Lawyers will also find a large niche as protection of 3DP intellectual property becomes a litigious challenge. Designs for products can be widely disseminated, and identical products can be produced by compatible printers, a situation that could replicate the software piracy challenge.

The reduced need for labor in manufacturing could be politically destabilizing in some economies that rely on traditional manufacturing for a large percentage of its labor force. Developing countries without large factories, however, may benefit by encouraging entrepreneurs to set up 3DP facilities for local consumption. These facilities would expand the countries' skilled labor forces and manufacturing sectors. By producing goods appropriate for local consumers, the country could rely less on expensive imports and reap the profits from local production.

Countries with aging societies would benefit from the ability to produce more goods with fewer people while reducing reliance on imports. This change could substantially increase overall productivity, which would otherwise fall as the ratio shifts toward fewer workers to support the growing proportion of elderly and retired. 3DP medical equipment and bioprinted organs and eventually targeted nanotherapies could

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[19] DARPA's "disruptive manufacturing technologies" program is described at http://www.darpa.mil/Our_Work/DSO/Progr3DPs/Disruptive_Manufacturing_Technologies_(DMT).aspx, accessed July 2011. DARPA has been supporting the overall development of 3DP processes.

[20] "3D printing will be a $5.2 billion market by 2020." http://money.cnn.com/video/technology/2011/06/02/t_tt_3d_printer_systems.cnnmoney/?source=cnn_bin&hpt=hp_bn3, accessed July 2011.

also significantly lower the cost of health care, which is expected to be a major drag on economic growth in coming decades.

In the long run, economic power and prosperity could shift toward leaders in the design and production of printers, the development of new materials for use by 3D printers, and the design of products to be printed. The U.S., the current overall leader in 3DP technology, could experience a renaissance in innovation, design, intellectual property exports, and manufacturing. Europe and other countries in the Organization for Economic Co-operation and Development also could be early benefactors from this manufacturing revolution. Germany is currently the leader in metal powder 3D printers. In addition, developing countries that are not major exporters could more rapidly improve their economic conditions and reduce dependence on producers of manufactured products such as China.

The strategic latency of 3DP is already evident in initial DIY successes in printing guns and high-capacity magazines for assault weapons. No doubt terrorists will find other uses for 3DP besides reducing their reliance on the weapons supply chain. Improvised explosive devices, for example, could be more easily disguised as ordinary civilian items. "Red Teams" in the defense and intelligence communities will no doubt envision many uses of the technology that reduce detection and increase the capacity of nonstate actors, especially terrorists, to engage in lethal activities.

There is little governments can or should do to stop the development of 3DP. Governments will have to hedge against possible and actual threats posed by this technology. However, so far such threats do not appear to include new types of lethal equipment but rather enhancing the ability to elude controls and detection in producing existing types of weapons. In the long run, however, there could be new classes of weapons developed with 3DP.

The geoeconomic impact of 3DP could affect the mission of the U.S. military. A decline of mass production at the end of long, complex supply chains could lead to a gradual reduction of global shipping. This could reduce the challenge of protecting sea lanes with naval forces. Presumably raw materials will continue to move around the planet by ship, but total shipping would likely be sharply reduced.

Increased resource productivity through 3DP could also lower quantitative demand for natural resources, thereby reducing the likelihood of resource conflict. Moreover, the potential economic stress of resource scarcities—higher prices in volatile regions—could also reduce the likelihood of military conflicts threatening U.S. interests and the prospect of U.S. military intervention. The economic and environmental relief offered by 3DP could include easing demand for livestock through 3D bioprinting[21] of meat, poultry, and fish as the growing middle class seeks to literally "move up the food chain."[22]

3DP will not only change the national security environment for the military but also the way it operates. The U.S. military is already benefiting from 3DP medical advances in printing skin and prosthetics. The military is likely to spur further medical developments that enhance the survival and rehabilitation of injured personnel. The military could benefit substantially from requiring defense contractors to provide the intellectual property and the computer files for most if not all parts of every weapons system. With the resources and rights to produce all spare parts, the military can speed repairs and realize huge savings in maintenance costs. In the longer term, 3DP provides the opportunity to substantially redesign weapons

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[21] See, for example, the initial efforts of Modern Meadow at http://modernmeadow.com/. See also Lipson and Kurman's *Fabricated*, 148.

[22] Some indication of the dramatic rise in meat consumption with the rise of the middle class can be seen in the growth of meat consumption in China from 8 million tons at the beginning of the country's reform process in 1978 to 71 million tons in 2012—nearly a 900 percent increase. Christina Larson, "Losing Arable Land, China Faces Stark Choice: Adapt or Go Hungry," *Science*, **339**, 664–665.

systems. These redesigns could reduce the cost, weight, and complexity of systems while increasing their capabilities and effectiveness.[23]

3DP could eventually provide the military with the ability to print food at any point of consumption, thus reducing the cost of food itself as well as the cost of protecting food shipments. Bioprinting of meat, fish, and poultry will be possible as well as printing of synthetic food from raw materials that would be relatively easy to ship and store.[24]

The military will have the opportunity to take advantage of its own personnel as DIY makers, even in the field, for "bottom up" and" just-in-time" innovation. In the coming decade, a substantial percentage of military recruits likely will have had extensive experience with 3DP in high school classes and elsewhere—just as today's recruits grew up with the Internet, video games, and social media. Smart militaries will be prepared to capitalize on this likely eventuality.

The World Forever Changed

The 3DP revolution is occurring at both the high end and the low end, and converging toward the middle. One end of the technology spectrum involves expensive high-powered energy sources and complex scanning algorithms. The other end is focused on reducing the complexity and cost of a well-established 3DP processes to bring the technology to the general public. Major advances will continue to be made in both directions in the next five years. "Direct metal" processes will continue to advance as process control and our understanding of fundamental metallurgy improves. These cutting-edge technologies will gain broader acceptance and use in industrial applications as the necessary design, manufacturing, and certification standards emerge. On the other hand, the quality and complexity of parts created by the desktop-machines will continue to improve while the cost declines. In the next few years, these systems will also see broader dissemination into school classrooms and homes.

The pace of development and implementation of 3DP is, of course, uncertain and likely to vary widely for different types of manufactured products. For a long time, many consumer products may be cheaper to mass produce by traditional methods and shipped to points of consumption. Nevertheless, there will likely be tipping points in various fields of production at which it becomes necessary for manufacturers to change to the new process or lose their competitive edge and risk extinction. This process will likely be uneven and could take many years longer in some areas than in others.

The impact of 3DP on manufacturing, the environment, the global economy, and geopolitics is likely to occur gradually over several decades. But the cumulative impact is likely to be disruptive and revolutionary, as it has been with personal computers, the Internet, and mobile computing. That technology reached a "tipping point" and went mainstream, transforming the way people operate across virtually all sectors, including business, government, education, and personal lives.

Foreseeing the specific developmental paths and timetables as well as the economic, social, political, and security effects and implications of these technologies is not possible. Virtually no one foresaw Google, Facebook, or the iPhone even a decade before each was created. But analysts did forecast broad, revolutionary implications of the Internet. So, too, can we foresee that 3DP will "revolutionize the way we

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[23] For further implications of 3DP for the military, see Col. J. R. Drushal, U.S. Army War College Fellow, "Additive Manufacturing: Implications to the Army Organic Industrial Base in 2030," Atlantic Council, 2013.

[24] Regarding bioprinting meat, see Neal Pierce, "Finding 'Meatless' Meat for a World of Cities," *Seattle Times*, February 25, 2013, http://seattletimes.com/html/opinion/2020433414_peircecolumnmeatlesscitiesxml.html, and the website for Modern Meadow, which is a leading company in bioprinting meat, http://modernmeadow.com/. Regarding printing synthetic food, see Lipson and Kurman's *Fabricated*, 147–151.

make almost everything" with huge implications for society, even if the timing and shape of this technology's strategic latency are not completely discernable now.

The impact of 3DP could go beyond transforming the manufacturing process and rebalancing the global economy, especially if it contributes to changing the trajectories of some of the most worrisome trends in environmental degradation, resource scarcity, and climate change. 3DP's benefits for protecting the environment and developing a sustainable global economy could be even more significant than its effects on the global economy. The national security implications of 3DP thus extend far beyond the threats of printing guns and improvised explosive devices and the benefits of reducing military equipment costs and procurement time for spare parts. 3DP can help create a safer world in which national security planners face less poverty, political instability, and military conflict by reducing the environmental impact of human activity, from climate change to resource depletion, while improving the lives of billions of people.

Country Case Studies, an Introduction

by Michael Nacht

The third section of this volume presents three detailed country case studies plus a comparative analysis of innovation in three others to illustrate the diversity of how strategic latency is interpreted and implemented by different national governments. These case studies are not intended to be illustrative of all the approaches to latency. Instead, they represent a sampling of critically important nation-states and explain how each approaches the issue reflective of their individual strategic cultures.

Dr. Tai Ming Cheung notes that although there is no precise term for "strategic latency" in Chinese, the People's Republic has adopted a policy of "yujin yumin" to "achieve the mutual advancement and coordinated development between defense and civilian technology." He details how China exploits foreign technology transfer through a four-step process—introduce, digest, absorb, re-innovate—in order to harness civilian technological and industrial capabilities for military purposes.

Turkey may not be thought of as a technological leader, but Dr. Zev Winkelman and Prof. Michael Nacht offer a wealth of information and analysis primarily about Turkey's adoption of nuclear energy for civilian purposes as a possible hedge, or precursor, to a nuclear weapons program. These latent capabilities are examined within the context of Turkey's difficult relations with its neighbors, including Iran, Syria, and Pakistan, as well as in the context of its ongoing Kurdish rebellion and a history of military coup d'états.

Japan, by contrast, is widely recognized as among the most advanced technological societies. The chapter by Ms. Carolyn Chu and Prof. Michael Nacht examines the labyrinth of Japan's advanced technology network, including government, university, and private-sector facilities. The authors note the enormous inhibitions created by a lack of political will to produce weapons of mass destruction, which was reinforced by the Fukushima nuclear accident. However, these constraints co-exist with Japan's concerns about regional tensions, fueled by suspicions about North Korean and Chinese intentions. Chu and Nacht highlight the tension between Japan's security needs and its possession of civilian technologies that could be exploited for advanced military purposes.

A final chapter offers a comparative analysis of innovation in Brazil, Russia, and South Korea. Dr. Stephanie Shipp and a team of researchers explore how national efforts to spur innovation depend on relationships among a state's natural, cultural, demographic, and geographic endowments. Governments and the private sector must leverage those endowments skillfully to stimulate the development of strategic technologies. Utilizing this framework, the authors summarize the approach taken toward innovation in Brazil, Russia, and South Korea, including the strengths and limitations of national institutions, such as South Korean *chaebols*, which stimulate rapid economic growth but also stifle competition.

The country case studies illustrate how governments attempt to derive economic, political, and military power from emerging technologies, sometimes acquiring latent capabilities as a hedge against future threats.

Strategic Latency with Chinese Characteristics: The Quest to Realize Its Strategic Potential in the 21st Century

by Tai Ming Cheung

Napoleon Bonaparte may have been one of the earliest exponents of the concept of strategic latency when he supposedly remarked that China was a "sleeping giant" that would "shake the world" when awakened. This notion of a dormant colossus beginning to stir has become a bumper sticker description of China's ascent as a world power. But how does a huge underdeveloped country go about realizing its strategic potential?

Transforming latent promise into actual capability is one of China's foremost priorities. While the country is growing stronger economically, it lags behind in the military and science, technology, and innovation (STI) domains. This chapter explores the approaches that China is pursuing to unlock its strategic STI potential, especially for national security applications. First is the development of a dual-use economy to exploit synergies in the civilian and defense realms. Second is the assimilation of foreign technology transfers.

Strategic Latency and Its Application to China

Strategic latency, as defined by Zachary Davis, is "the inherent potential for technologies to bring about significant shifts in the military or economic balance of power."[1] Davis explains that "such potential may remain unexploited or even unrecognized, and thus latent, until a combination of national security, economic, and organizational factors coalesce to produce powerful capabilities."[2]

A core issue in this definition is why the technological potential is unexploited or unrecognized. There are two general possibilities. First, is it because of political restraints in which a country's leadership decides not to pursue development for domestic and/or external factors? This scenario can be termed restrained latency. Or secondly, are the primary reasons for this latency because states lack the economic resources and technological expertise to be able to afford to develop, produce, and operate these capabilities? This scenario can be labeled constrained latency. It may also be a combination of these two possibilities. Dividing strategic latency into restrained or constrained variants offers a useful starting point for getting to the roots of why states do not exploit technological opportunities.

This is especially the case for the People's Republic of China, which has on a number of occasions refrained from engaging in the exploitation of major technological capabilities with important external strategic and defense implications. In examining the Chinese track record on strategic latency, three periods can be distinguished.

Under the reign of Mao Zedong between the 1950s and the late 1970s, China primarily practiced constrained latency because it lacked the scientific, technological, and economic resources to make major advances in the acquisition of significant technological capabilities. A key area was China's development of nuclear weapons and accompanying strategic delivery systems, such as ballistic missiles and submarines.[3] China made enormous investments in these areas during the 1960s and 1970s. Although China became a nuclear state as well as a space power during this period, these capabilities were technologically limited,

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1 There is no equivalent Chinese term for strategic latency. The closest literal translation would be *Zhanlue Qianfu* (战略潜伏) or *Zhanlue Qianli* (战略潜力), which mean strategic potential.

2 Zachary S. Davis, "Strategic Latency and World Order," *Orbis,* Winter 2011.

3 See Tai Ming Cheung, *Fortifying China* (Ithaca: Cornell University Press, 2009), Chapter 2.

with a lack of advanced manufacturing facilities for production on any significant scale. This is perhaps an important reason why China opted for a minimal nuclear deterrence strategy.

The second period was between the 1980s and 1990s when Deng Xiaoping was in charge. He pursued an accommodationist grand strategy toward the outside world that emphasized "keeping a low profile and biding time." Under this approach, the overwhelming emphasis was on economic development. Even as the country became more prosperous and more technologically capable, there was little leadership appetite to engage in pursuing strategic and defense-related technological capabilities. Restrained latency became the principal rationale during this period.

Since the middle and late 1990s, the "handbrake" of strategic latency on Chinese strategic and defense science and technology (S&T) development has been lifted, and the Chinese authorities have been engaged in an intensive and concerted effort to fully realize the country's STI potential, especially for national security applications. The principal rationale for this major shift in direction is that the Chinese leadership and defense establishment see an increasingly complicated and perilous external environment that threatens China's national security.

These threats come from a number of areas. First, beginning in the early 1990s, the Chinese leadership became extremely worried that Taiwan would seek to declare independence and end the long-standing consensus across the Taiwan Strait of a single Chinese motherland. Beijing made clear that this possibility was politically unacceptable, and it would use force to deter and prevent Taiwanese independence from taking place.

Second, the 1991 First Gulf War and the overwhelming technological superiority that the U.S. and allied forces enjoyed and used so effectively made clear to Chinese military leaders that the world was going through a revolution in military affairs. China needed to catch up or get left behind.

Third, in 1999 the U.S. bombed the Chinese Embassy in Belgrade. The Chinese leadership's reaction was to sharply intensify efforts to develop strategic weapons systems, or what the People's Liberation Army terms "assassin's mace" or *Shashoujian* capabilities. According to Gen. Zhang Wannian, who was a vice chairman of the Central Military Commission (CMC), the country's highest military decision-making organ, during the Belgrade Embassy crisis, the CMC convened an emergency meeting immediately following the bombing. One of the key decisions made at the meeting was to "accelerate the development of *Shashoujian* armaments."[4] Zhang pointed out that Jiang Zemin was especially insistent on the need to step up the pace of development of *Shashoujian* mega-projects, saying that "what the enemy is most fearful of, this is what we should be developing."[5] Because the "enemy" was the U.S., the implication was that the defense and strategic science, technology, and innovation systems should be engaged in developing asymmetric capabilities targeting U.S. vulnerabilities. These leadership calls appear to have been turned into a major weapons technology and engineering development program, known as the 995 Project.[6]

In China efforts to intensify the development of its strategic and defense capabilities, it is employing a number of approaches to realize the inherent potential in its civil and defense apparatuses. The first is the development of a dual-use civil–military economy. The second is the embrace and exploitation of foreign technology transfers.

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4 Zhang Wannian Writing Team, *Biography of Zhang Wannian* (Beijing: Liberation Army Press, 2011), 416.

5 Ibid., 419.

6 There is no official Chinese acknowledgement of the 995 Project, but there are occasional allusions to it in media reports, writings by Chinese military analysts, resumes of Chinese scientists, and project listings of university laboratories and companies engaged in defense-related work. See, for example, Zeng Li, "Investment in Defense Science and Technology," *Science and Technology Daily*, April 30, 2009.

Unlocking China's Strategic Potential: Building an Integrated Civil-Military Economy

Ever since the founding of China's communist state, the country's policy makers have voiced their aspirations for integrating the civilian and military halves of the economy. In the 1950s and 1960s, Mao Zedong and Zhou Enlai urged greater civil–military industrial coordination and cooperation,[7] but these statements were directed at encouraging the dominant defense economy to engage in civilian production. Little effort was made to pursue civilian-to-military transfers as the national economy was already heavily geared toward serving military needs. Leadership interest in civil–military integration issues ended with the rise in Cold War tensions and the onset of domestic political upheavals during the 1960s and 1970s that led to increased demand for military production.

Attention turned to civil–military integration when Deng Xiaoping assumed power in the late 1970s. He adopted the *Junmin Jiehe* 16-character slogan as state policy to guide the implementation of an aggressive military to civilian conversion program. With priority on harnessing the defense industry to support the development of the civilian economy, leadership interest was initially scant in promoting spin-on (civilian-to-military) initiatives. The overriding focus of the *Junmin Jiehe* policy during the 1980s and much of the 1990s was on the conversion of the defense sector to civilian use. But an important exception to this one-way flow in resources and knowledge was the establishment of the 863 Program in 1986. This initiative was the first significant effort by the authorities to pursue genuinely coordinated civil–military research and development (R&D). With its primary focus on raising China's long-term technological competitiveness and national security, the 863 Program became an important pioneering mechanism by which the defense economy was able to harness the capabilities of the civilian economy directly for military applications. Outside of the 863 Program, however, the overwhelming focus was on defense conversion and little attention was paid to spin-on activities.

Although the near-myopic concentration that the authorities and defense industry devoted to military-to-civilian conversion during the 1980s continued well into the next decade, fledging interest began to appear from the early 1990s into civilian-to-military technology transfers and the broader issue of how the defense economy could effectively harness the capabilities of the civilian economy. While defense conversion was the dominant paradigm during this period, policy makers began to ask if this would continue to be the case in the next century. They began to tentatively cast their eye toward how the country's buoyant economic development could be harnessed for military utilization.

Defense conversion played an important role in breaking down the formidable barriers that insulated the defense economy from the rest of the national economy. The conversion allowed for increasing interaction between defense enterprises and civilian counterparts. While the overwhelming focus was on military-to-civilian transfers, the establishment of channels of communications and cooperation would eventually lead to the opportunity to explore and develop dual-use and spin-on initiatives from the late 1990s.

A crucial breakthrough in the development of a dual-use economy was the willingness of decision makers in the mid-1990s to accept not only the premise that the building of an integrated civilian–military economy should be a strategic goal of the country's 21st century economy, but also that this effort should be vigorously implemented. While Deng's notion of a seamless civilian–military economic structure had been codified as a state guiding principle at the beginning of the reform era, there had been little serious effort to carry it out in the face of entrenched opposition from the conservative and insular defense industrial bureaucracy. The generational changeover that took place throughout the top ranks of the party,

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7 See Wu Jianeng, "My Opinion on the 'Combining Military and Civilian, Combining Peacetime and Wartime' Guiding Principles of New China's Defence Technology and Industry," *Junshi Jingji Yanjiu* (Military Economic Research), July 2002, 34–36.

government, military and defense economy in the 1990s saw the promotion of a younger crop of "third-generation" decision makers who were willing to embrace new ideas and policies that included the establishment of a dual-use economy.

Chief among the new crop of more technologically perceptive leaders was CMC Chairman and Communist Party General Secretary Jiang Zemin, who played a leading role in putting dual-use integration on the policy agenda. As an electrical engineer by training and electronics minister during the 1980s, Jiang had first-hand experience dealing with civil-military technological and industrial issues, especially military-to-civilian conversion.[8] From the beginning of the 1990s when he became CMC Chairman until his retirement in 2004, Jiang paid frequent visits to defense R&D facilities and military S&T units, and he personally identified himself with key defense-related high-technology projects such as the country's Shenzhou manned space program.

In 1999, the State Council held a conference on technological innovation and adopted a new high-level S&T policy statement that called for greater effort to promote the development, application, and commercialization of high technology.[9] The statement included a call to "vigorously develop civil–military dual-use technology . . . pay attention to bringing into play the vital role of high-technology in strengthening military capabilities."[10] This intensifying discussion of dual-use strategy influenced policy makers as they prepared the country's 10th Five-Year Economic Development Plan for the 2000–2005 period. The policy outcome was a new set of guiding principles contained in the plan that replaced Deng's original 16-character policy.[11] This new 16-character list of principles were: "*Junmin Jiehe, Yujun Yumin, Dali Xietong, Zizhu Chuangxin*":[12]

- *Junmin Jiehe* (Combining Civil and Military Needs): This principle commonly refers to defense conversion but can also include both the spin-off and spin-on processes.[13]
- *Yujun Yumin* (Locating Military Potential in Civilian Capabilities): This principle refers most directly to the forging of an integrated civil–military dual-use system, especially the establishment of a civilian apparatus that has the technological and industrial capabilities to meet the needs of the military and defense economy.
- *Dali Xietong* (Vigorously Promoting Coordination and Cooperation): This guidance seeks to uphold the organizational model of close cooperation between differing bureaucracies that led to the successful accomplishment of the country's nuclear, missile, and satellite programs.

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8 Yu Bencheng and Su Kuoshan, "An Account of How Jiang Zemin Shows Concern For the Building of Units Under the State Commission of Science, Technology and Industry for National Defense," Liaowang, July 28, 1997, 4–6.

9 "China Holds High-Level Conference on Technological Innovation," Environment, Science & Technology Section, U.S. Embassy, Beijing, August 1999.

10 "Decision of the Central Committee of the Communist Party of China and the State Council on Strengthening Technological Innovation, Developing High Technology and Realizing Industrialization," August 20, 1999.

11 Zhang Nanzheng and Zhang Shengwang, eds., Dangdai Guofang Jingji Lilun Qianyan Wenti Yanjiu [Research into the Forward Problems of Contemporary Defence Economic Theory] (Beijing: Guofang Daxue Chubanshe [National Defence University Press], 2003), 145–149.

12 "Outline of the 10th People's Republic of China Economic and Social Development Five Year Plan," Guangming Ribao, Chapter 24, March 18, 2001. These principles were formally announced at the Communist Party's Fifth Plenum in 1999. See Hu Lihua and Liu Zhihong, Jiang Zemin Guofang Keji Gongye Jianshe Sixiang Yanjiu [Research into the Thinking of Jiang Zemin on the Building of the Defence Science and Technology Industry] (Beijing: Dianzi Gongye Chubanshe [Electronics Industry Press], 2005), 145–150.

13 Zhang Nansheng and Zhang Shangweng, *Dangdai Guofang Jingji Lilun Qianyan Wenti Yanjiu*, 146–148.

- *Zizhu Chuangxin* (Conducting Independent Innovation): Self-reliance in the development of military equipment continues to be a central principle for the defense economy. To achieve self-reliance, greater emphasis is to be placed on cultivating a well-trained cadre of scientists and engineers, strengthening the R&D apparatus, and developing a robust intellectual property and patent system.

The Yujun Yumin Dual-Use Economy: Realizing Strategic Potential in the National Economy

While strategic latency does not have a corresponding Chinese term or idea, Chinese defense policy makers and planners do employ a concept, *Yujun Yumin,* which focuses on the inherent military attributes of the civilian economy and society. The emphasis in this concept, however, is on identifying how to exploit these capabilities. The 2004 Chinese Defense White Paper defined *Yujun Yumin* as the "reserving of military potential in civilian capability."[14] In other words, *Yujun Yumin* encompasses the full range of capabilities and resources available in the general economy and society, especially technology, that can be harnessed for military requirements.[15] The Western concept that would be most closely associated with *Yujun Yumin* is spin-on.

Chinese interest in dual-use and spin-on programs during the 1990s was directed to the development and acquisition of specific technological products. Little serious attention was devoted to the building of an institutional system that would systematically promote dual-use innovation. This uncoordinated piecemeal approach meant that progress in the development of civilian products with spin-on potential was slow and limited.[16] Structural and regulatory barriers in the defense and civilian economies were also serious impediments to dual-use technological exploitation. This challenge was especially the case for the nonstate-owned sector, which had emerged in the 1990s as one of the most dynamic and innovative parts of the economy. Nonpublic enterprises (which includes private and hybrid state–nonstate ownership) were explicitly prohibited by laws and regulations from taking part in defense industrial operations.[17]

Special dispensations bypassing these restrictions were occasionally granted to nongovernmental entities with close government or military ties that produced technologies sought after by the PLA. Huawei Technologies, for example, became an important supplier of telecommunications hardware to the PLA during the 1990s, even though it was not a government-owned enterprise. However, this situation was the exception rather than the rule because of the deep-seated misgivings that the defense industrial authorities had of the technological competence of the nonstate-owned sector.

In an effort to overcome these institutional barriers, the third plenum of the 16th Party Congress in 2003 gave the go-ahead for the construction of a new civilian technological and industrial base with embedded military capabilities. "The Decision of the Chinese Communist Party Committee on Several Issues in Perfecting the Socialist Market Economy" called for the building of an innovative *Junmin Jiehe, Yujun Yumin*-based system that focuses on the "mutual promotion and coordinated development of the defense

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[14] "China's National Defence in 2004," State Council Information Office, 74.

[15] *Yujun Yumin* is the term that Jiang Zemin first coined to describe this new civil–military economy. Additional terms have since been used to describe this rising dual-use system, of which *Junmin Ronghe* stands out and is the most commonly used since the late 2000s.

[16] Du Renhuai, "The Transfer of Military-Oriented Enterprises in China's Defence Industry," *Junshi Jingji Yanjiu,* July 2002, 22–23.

[17] Wu Yuguang, "Mingong Gaoxin Jishu Zhuan Mingong Wenti Pouxi" [Dissecting the Problem of The Transfer of Civilian Use High and New Technology for Military Use], *Keji Chengguo Zongheng* [Technological Achievement], June 2004, 24.

and civilian technological sectors."[18] This elevated the *Yujun Yumin* guiding principle into the strategic outline for the future dual-use economy.

The establishment of the *Yujun Yumin* system was made possible by two crucial developments in the reform process in both the wider national economy and the defense industry. On the one hand, the authorities have increasingly recognized the central role played by nongovernmental enterprises in the country's economic development, which has led to the gradual lifting of restrictions on their involvement in the economy. In an important step at the 2003 Party Plenum, nongovernmental firms were granted many of the same rights as state-owned enterprises.[19] This step was followed by the amendment of the state constitution by the National People's Congress in 2004 to cover the protection of private property for the first time since 1949.[20] These moves were a clear signal that the central leadership had decided to end the discriminatory second-class status of nonstate entities.

On the other hand, the structural reform and downsizing of the defense industry since the late 1990s has created a strategic opportunity for the involvement of civilian enterprises with no prior participation in defense industrial operations. A central goal of the overhaul of the defense economy is to establish a small inner core of dedicated defense prime contractors that is complemented by a large supporting base of secondary subcontractors (*Xiao Hexin, Da Xiezuo*).[21] The defense industrial bureaucracy is keen to attract not only existing military and former military entities into this outer pool but also mainstream civilian companies with advanced expertise and technology in areas of high military demand.[22]

The Commission for Science, Technology, and Industry for National Defense (COSTIND) and the defense industry, which had been cautiously examining the dual-use paradigm, were pushed into action by the Third Plenum's decision and rapidly devised an implementation strategy. One of the first concrete measures was the promulgation of a set of regulations by COSTIND in May 2005 that for the first time formally granted permission for nonstate and foreign-funded enterprises to participate in the development and production of military equipment.[23]

A central tenet of the 2003 decision on building the *Yujun Yumin* system was to "achieve the mutual advancement and coordinated development between defense and civilian technology."[24] While this ostensibly called for the fostering of a balanced approach that would serve both military and civilian needs, in reality the primary intention was to harness civilian technological and industrial capabilities for military purposes. Spin-off activities were considered a secondary priority because they had already enjoyed more than two decades of robust growth and government support.

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[18] "'Decision' on the Direction of the Science and Technology Industry," *Zhongguo Gaoxin Jishu Changye Daobao* [China High New Technology Industry Newspaper], October 29, 2003.

[19] "Party Vows to Further Improve Market Economy," *People's Daily English Edition*, October 15, 2003, http://english.people.com.cn/200310/15/eng20031015_126021.shtml

[20] Zhang Le and Zhang Yong, "Non-Public Economy is Granted 'Full Access,'" *Xinhua Domestic Service*, March 12, 2003.

[21] See Sun Guangyun, *Zhongguo Guofang Keji Gongyede Gaigehe Fazhan Wenti* [The Problems of the Reform and Development of the Chinese Defence Technology Industry] (Beijing: Hangkong Gongye Chubanshe (Aviation Industry Press), 2003), 82–106.

[22] See Wu Yuanping, Zhao Xinli and Zhao Junjie, *Xin Zhongguo Guofang Keji Tixi De Xingcheng Yu Fazhan Yanjiu* [Research into the Formation and Development of New China's Defence Science and Technology System] (Beijing: Guofang Chubanshe [Defence Industry Press], 2006), 389–400.

[23] "China Opens Weapons Production to Private, Foreign-Funded Businesses," *Xinhua Domestic Service*, May 27, 2005.

[24] "'Decision' on the Direction of the Science and Technology Industry."

While the principal method of technology and knowledge flow in the *Yujun Yumin* system is the spin-on conversion of civilian products and processes for military application, a number of other forms of civilian-to-military transfer mechanisms are used.[25] They include the simultaneous development of commercial and military technology that is typified by the 863 Program and, more broadly, the building of a mobilization system that can rapidly transform the peacetime economy for wartime utilization.

Exploitation of Foreign Technology Transfers

Another important approach that China is using to realizing strategic technological potential is the heavy reliance on foreign sources for technology and knowledge, although it is combined with increasing levels of domestic input. This is what the Chinese leadership means when it promotes the concept of "indigenous innovation," which is defined in the country's 2006–2020 Medium and Long-Term S&T Development Plan (MLP) as a way to promote original innovation by re-assembling existing technologies in different ways to produce new breakthroughs and absorbing and upgrading imported technologies.[26]

A more accurate and precise way to define this aspect of China's technological development strategy is a four-part process known as "introduce, digest, absorb, and re-innovate", (**引进***Yinjin*、**消化** *Xiaohua*、**吸收** *Xishou*、**再创新** *Zai Chuangxin*), or IDAR, which refers to the different steps required to turn foreign technology into a remade domestic variant. This technology absorption strategy is most clearly articulated in a supplementary document to the MLP that calls for encouraging the introduction of advanced foreign technology that can be digested and absorbed for re-innovation.[27] The document, entitled "Opinions to Encourage Technology Transfer and Innovation and Promote the Transformation of the Growth Mode in Foreign Trade," was issued by a group of eight powerful government economic, financial, and planning agencies that included the National Development and Reform Commission, Ministry of Finance, and Ministry of Commerce.

The central goal of the "Opinions" is to build a sophisticated advanced apparatus that brings in foreign technology transfers and allows for the effective absorption and re-innovation of products that China can effectively claim to be homegrown. A number of industrial sectors are highlighted that would benefit from this approach, including information communications technology, biotechnology, civilian aviation and aerospace, advanced materials, and machinery manufacturing.[28] Key initiatives that are emphasized include:

- Actively seek bilateral and multilateral technical cooperation.
- Improve and expand open-source international information services that can be disseminated to local actors.

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[25] See John Alic, et al., *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992), 64–75.

[26] "Guidelines for the Medium- and Long-Term National Science and Technology Development Program (2006–2020)," State Council, June 2006.

[27] "Opinions to Encourage Technology Transfer and Innovation and Promote the Transformation of the Growth Mode in Foreign Trade," Ministry of Commerce, National Development and Reform Commission, Ministry of Science and Technology, Ministry of Finance, General Customs Administration, General Tax Administration, State Intellectual Property Office, and State Foreign Exchange Office, July14 2006, http://www.most.gov.cn/ztzl/gjzctx/ptzcyjxh/200802/t20080225_59303.htm (in Chinese).

[28] For an example of how one industry implemented this strategy, see "Railway Ministry: Our Country's Railway is About How to Introduce, Absorb, and Re-Innovate," Xinhua News Agency, April 29, 2007

- Encourage and help firms to go abroad to gain access to foreign research and development knowledge.
- Attract more multinational firms to set up R&D institutes and facilities in China.

Introducing Foreign Technology

Gaining access to external knowledge is vital for China's defense and civilian S&T systems to compensate for the gaps and inadequacies in their research and development base and in order to meet ambitious development targets. China's multitude of acquisition and technology transfer mechanisms and channels include (1) arms and technology imports; (2) foreign direct investment and direct (explicit technology transfer agreements) and indirect (transfer of governance and other types of less tangible soft skill sets) spillover effects;[29] (3) espionage through traditional industrial- and information-era cyber operations; (4) open-source information collection and analysis; (5) establishment of foreign R&D centers; and (6) human capital transfers and exchanges. The most important of these channels for the Chinese defense S&T system are arms and defense technology-related imports, espionage, and open-source information collection and analysis.

China is one of the world's largest arms importers and exporters. The Stockholm International Peace Research Institute estimates that China was the world's largest arms importer between 2003 and 2007 with a global share of 12 percent and ranked second between 2008 and 2012 with a 6-percent share.[30] The lion's share of China's arms imports and defense technology transfers since the 1990s has come from Russia.

In the face of long-term international restrictions on defense-related technology transfers, two of the primary mechanisms that the Chinese defense S&T system employs to mitigate these limitations are open-source information collection and espionage activities. For open-source information collection, China has built a substantial infrastructure that dates back to the 1950s and initially was created to support the country's construction of its strategic nuclear weapons and ballistic missile capabilities. Information collection is an integral element of the information analysis and dissemination (IAD) system, which will be assessed in the next section on assimilation.

Espionage also plays an important and growing role in China's defense acquisition efforts, although its value is difficult to gauge because of the lack of transparency. It occurs in two forms: industrial espionage and computer network exploitation or cyber espionage. Traditional industrial espionage has been the bread and butter of China's spying efforts since the founding of the communist republic. However, its impact on improving the Chinese defense S&T system appears to have been limited and episodic until the beginning of the 1990s because of the country's economic and technological isolation from the global defense economy.

An important turning point in China's industrial espionage efforts took place in the early 1990s with the collapse of the Soviet Union. The collapse allowed China to take advantage of the economic chaos in Russia and former Soviet republics and gain access to their defense industrial facilities and scientific and

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[29] This is the standard approach to civilian commercial technology transfers. For useful studies examining China and international technology transfer, see Giuditta De Prato and Daniel Nepelski, "International Technology Transfer Between China and the Rest of the World," European Commission Joint Research Centre Institute for Prospective Technological Studies, Working Paper, 2013; John Van Reenen and Linda Yueh, "Why Has China Grown So Fast? The Role of International Technology Transfer," 2012, http://cep.lse.ac.uk/pubs/download/dp1121.pdf; and Albert G. Z. Hu, Gary H. Jefferson, and Qian Jinchang, "R&D and Technology Transfer: Firm-level Evidence from Chinese Industry," *The Review of Economics and Statistics*, **87**(4), 780–786. For a perspective on civilian and dual-commercial technology transfers in the 1990s, see "U.S. Commercial Technology Transfers to People's Republic of China," Bureau of Export Administration, U.S. Commerce Department, 1999.

[30] http://www.sipri.org/research/armaments/transfers/measuring/recent-trnds-in-arms-transfers.

engineering personnel. During the 1990s, hundreds of Russian defense scientists and engineers were recruited and brought to China to provide expert advice.[31] There has also been a proliferation of cases that show intensive Chinese intelligence-gathering activities taking place in the former Soviet Union. For example, the Russian chief executive of a rocket and missile company was imprisoned for illegally providing missile design information to China Precision Machinery Import-Export Corporation in 2007.[32]

Access to former Soviet defense technology may have helped select portions of the Chinese defense industry to advance by at least one or more generations. The most significant contributions have been in fighter aircraft programs, air-to-air missiles, radars, fire-control systems, aircraft carrier and other naval systems, and manned space.

Digestion

In the digestion of foreign technology and knowledge, a key mechanism that China has cultivated since the formative years of developing its S&T R&D system in the 1950s has been its IAD apparatus.[33] A key rationale for the historical development of the IAD system was to provide information on global S&T developments to civilian and military S&T and academic organizations that were largely isolated from the outside world during the regime of Mao Zedong between the 1950s and 1970s. The output of this system consisted not only of the acquisition, collation, and translation of foreign S&T literature but also of specific technical information of direct utility to R&D organizations, especially for nuclear, space, and computational outfits.[34]

A number of major IAD entities were established within the S&T system, including the Institute of Scientific and Technical Information of China, which belonged to the State Science and Technology Commission (now the Ministry of Science and Technology), and the Electronics Science and Technology Intelligence Research Institute presently affiliated with the Ministry of Industry and Information Technology. The IAD system consists of approximately 400 analysis and diffusion centers with about 50,000 personnel, according to a 2006 assessment.[35] However, only about 35 of these organizations belong to central government agencies, and the rest are affiliated with provincial or lower level institutions.[36]

The vast majority of external information that IAD organizations analyze comes from open sources such as media and online and academic outlets.[37] The classified intelligence collected by PLA intelligence agencies is likely to be only available for the military component of the IAD system, centralized under the

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[31] Interview with senior Russian Defense Ministry official, Moscow, April 1993, and reported in Tai Ming Cheung, "China's Buying Spree," *Far Eastern Economic Review*, July 8, 1993. See also Tai Ming Cheung, "Ties of Convenience: Sino-Russian Military Relations in the 1990s," in Richard H. Yang, ed., *China's Military: The PLA in 1992/1993*, (Boulder, CO: Westview Press, 1993).

[32] "Reshetin Sentenced to 11.5 years for Passing Technology to China," *RIA-Novosti News Agency*, December 3, 2007.

[33] William C. Hannas, James Mulvenon, and Anna B. Puglisi, *Chinese Industrial Espionage: Technology Acquisition and Military Modernization* (London: Routledge, 2013), Chapter 2.

[34] Ibid., 20–21.

[35] Xu Guanghua, "The Development of the S&T Information Industry in the Building of an Innovation Country," Speech at the 50th Anniversary of the Institute of Scientific and Technical Information of China, October 16, 2006.

[36] Hannas, et al, *Chinese Industrial Espionage. . . .*, 22.

[37] One study suggests that 80 percent or more of S&T technical information requirements can be obtained from open-source publications, while the remainder need to be collected from "special means." Huo Zhongwen and Wang Zongxiao, *Sources and Techniques of Obtaining National Defense Science and Technology Intelligence* (Beijing: Science and Technology Literature Press, 1991), 84–85.

China Defense Science and Technology Information Center (CDSTIC) and affiliated with the General Armament Department. CDSTIC has grown rapidly over the past few decades, especially since the end of the 1990s, to cope with intensive demand for its S&T information and analysis services from the defense innovation system, military organizations, and the country's leadership.[38]

Concerted efforts have been made to improve the ability of the IAD system to assimilate and disseminate information in a timely and organized fashion. Efforts include the development of Internet-based and closed intranet S&T databases and information retrieval networks. CDSTIC, for example, operates an engineering technology information network, an all-army equipment S&T information network, a General Armament Department-specific S&T intelligence network, and an online digital library.[39] Each of the country's six defense industrial sectors also has its own IAD organizations that act as clearinghouses for specialized S&T information. These organizations, which range in size from 200 to 500 researchers, are attached to one of the principal conglomerates responsible for their sectors.[40]

Absorption

A central goal in China's development of its national-level and defense absorptive capacities is to promote the ability to carry out its IDAR strategy. The IDAR approach is being actively pursued by defense and high-technology intensive industries whose gaps in technological capabilities can be addressed using external technology transfers.[41] This strategy is carried out through an assortment of approaches that include collaborative international joint ventures as well as illicit transfers and unauthorized reverse engineering.

The Chinese authorities are investing heavily in building up an extensive technology and engineering ecosystem that supports efforts to combine digested foreign and local technologies. This investment has included establishing an extensive array of such entities as national engineering research centers, enterprise-based technology centers, state key laboratories, national technology transfer centers, and high-technology service centers. It also includes recruiting foreign technical experts through organizations such as the State Administration of Foreign Experts Affairs. National engineering research centers are one of the most important types of institutions designated by the Chinese government for transforming acquired and digested external technology into actual output. Nearly 300 of these research centers were in operation in 2013, and some of their key goals are:[42]

- To promote the transfer of advanced technologies and manufacturing processes for large-scale industrial production.
- To enhance innovation ability by digesting and assimilating technologies introduced from abroad and re-creating new technologies through international cooperation and exchanges.

The commercial and military aviation and high-speed rail sectors are at the forefront in the implementation of the IDAR strategy. The development of China's first narrow-bodied jet airliner, the C919, is a prime

38 "Science and Technology Vanguard, Think Tank for Decision-Making," *Zhongguo Jungong Bao*, November 17, 2012.

39 Ibid.

40 See http://www.dstpc.org for introductions to most of these entities.

41 This is how the Ministry of Railways described its technology innovation strategy in the late 2000s. See "Railway Ministry: Our Country's Railway is About How to Introduce, Absorb, and Re-Innovate," *Xinhua News Agency*, April 29, 2007, http://news.xinhuanet.com/politics/2007-04/29/content_6043932.htm.

42 "Administrative Measures on National Engineering Research Centers," National Development and Reform Commission, March 5, 2007.

example of this approach. Chinese aviation firms are mainly responsible for building the fuselage and other less technologically advanced portions of the plane while Western companies are providing the engines, avionics, and other technologies that China lacks.

In the C919 program, the external technology absorptive process is occurring throughout the entire research, development, and acquisition (RDA) cycle, from initial design to manufacturing. One of the lessons that the Chinese may have learned is that the earlier external technology transfers are introduced into the RDA process, the greater the benefits will be in terms of the speed of development and the quality of the finished product.

Re-Innovation

A major challenge for the Chinese defense economy is to turn its efforts in acquisition, assimilation, and transformation into exploitation or actual output. While there is a growing list of advanced weapons projects, from fifth-generation combat aircraft to turbofan jet engines at various stages of the RDA process, a major bottleneck is underdeveloped advanced manufacturing capabilities that are critical for the precision production of high-technology products.

The Chinese authorities have made the development of civilian and defense-related advanced manufacturing capabilities a leading priority in their S&T and economic development plans. This includes the Medium- and Long-Term S&T Development Plan and the 2012 Strategic Emerging Industries Plan. Moreover, the Ministry of Information and Information Technology issued a five-year program in 2012 providing a detailed outline of the development of the country's high-end equipment manufacturing industry. MIIT noted that China's advanced manufacturing industry lagged well behind the global frontier, its innovation ability was "weak," and "core technologies and core key components are in the hands of others."[43] Revenue from high-end equipment manufacturing accounted for only 8 percent of total revenues of the country's equipment manufacturing industry in 2012.

While these S&T development plans stress the importance of nurturing homegrown S&T capabilities, the reality is that China can only make major progress through gaining access to foreign technologies and know-how. The high-end equipment manufacturing industry development plan calls for conducting "secondary innovation based on the introduction and absorption of technologies," which is an oblique reference to the strategy of combining and integrating advanced foreign technology with domestic capabilities. The plan puts forward a number of key industrial areas for the acquisition and development of high-end equipment manufacturing capabilities that include (1) aviation manufacturing sector, especially for 150-seat or larger passenger aircraft and aviation engines; (2) satellite industry; (3) rail transportation industry, especially high-rail trains; (4) marine engineering industry, especially deep-sea submersibles; and (5) intelligent manufacturing equipment industry, especially for high-end numerical control machine tools, precision manufacturing technology, and simulation software for large-scale complex equipment and systems.

Industrial- and cyber-espionage activities and other illicit and grey acquisition strategies are likely to figure prominently in China's efforts to achieve its development goals in these priority areas as well as in sensitive defense and dual-use technologies. This approach has worked especially well in the building of China's high-speed rail sector, which is one of the priorities in its high-end equipment manufacturing development plan. European and Japanese firms provided significant amounts of illicit high-speed rail technology transfers to China during the 2000s. These transfers allowed the Chinese rail industry to replicate and improve upon these capabilities within five years and produce what they insisted were brand new

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[43] "12th Five Year Program for Development of High-End Equipment Manufacturing Industry," Ministry of Information and Information Technology, July 9, 2012.

generations of "re-innovated" trains. Many of the foreign firms involved in these technology deals have been reluctant to publicly criticize the Chinese for reverse engineering their products, although Japanese firms have been more vocal in their protests.[44] China's 12th Five-Year Development Program for the Rail Transportation Equipment Industry, published in 2012, acknowledged that its high-speed rail sector was based on "secondary innovation of absorbed technology introduced from abroad."[45]

Foreign rail firms were surprised how quickly their Chinese counterparts were able to absorb and reverse engineer these advanced technologies. While the Chinese rail industry benefited greatly from the extensive level of technology transfers, it also invested heavily in building a robust absorptive capacity infrastructure that included the establishment of a state-of-the-art national rail transportation research laboratory, a state engineering technology research center, a state engineering research center, and more than a dozen national-level enterprise technology centers.[46] These research, development, and engineering bases are also being laid down in many other industrial sectors, and they are an essential component of China's growing absorptive capacity.

Conclusions

China today is pressing ahead to exploit and realize its strategic potential as quickly as possible and become a leading S&T power. Consequently, there is little place for strategic latency to exist in its policies or strategic thinking. Indeed, China maybe one of the most important catalysts within the global S&T system to spark a new round of technological competition by pushing other states to follow suit in their approaches to technological development and exploitation, especially key strategic rivals such as the U.S. and Japan.

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[44] "Train Makers Rail Against China's High-Speed Designs," *Wall Street Journal*, November 17, 2010.

[45] "12th Five-Year Development Program for the Rail Transportation Equipment Industry," which is contained in "12th Five Year Program for Development of High-End Equipment Manufacturing Industry."

[46] Ibid.

Turkey: Within Range?

by Zev Winkelman and Michael Nacht

Turkey is an important example of a nonnuclear-weapon state building up its scientific expertise, technical capabilities, and nuclear material inventory to the point where it is simultaneously within range of a breakout nuclear weapons capability and yet not in violation of any international norm or agreement. New techniques for laser enrichment of uranium, moreover, could facilitate this crossover. Moreover, Turkey's advancing capabilities in a variety of scientific fields place it in a position to exploit them for military purposes.

Whether considering strategic changes in absolute, relative, global, or regional terms, all elements of national power—diplomatic, informational, military, and economic—are prevalent in Turkey.[1] Each of these elements can be affected by and in turn affect new developments in science and technology (S&T). In Turkey, each of these dimensions of power has recently experienced shifts that may prove to have strategic consequences.

With a population of more than 75 million and straddling a vital intersection between Europe and the Middle East, Turkey is positioned to play an increasingly important role in some of the major geostrategic issues of the 21st century. A NATO member since 1952 and the first Muslim-majority country to recognize the state of Israel in 1949, Turkey has emerged in the past decade as a highly significant independent political force in the Middle East with long-term strategic goals that could continue to distance it from the U.S. and the West. Turkey denied U.S. troop access in the prelude to the Iraq War in 2003, although it later contributed almost 1,800 troops to the International Security Assistance Force in Afghanistan.

Turkey has virtually dissolved its diplomatic relationship and ceased all military and intelligence cooperation with Israel (despite attempts to repair them in 2013), especially after the altercation over a blockade-busting effort by a Turkish nongovernmental organization (NGO) to deliver aid to the Gaza Strip in defiance of Israel in 2010 (although a diplomatic settlement is, at this writing, within sight). The Turkish government has taken an independent and prominent role in the 2011 Arab spring revolts in Egypt and Libya, although in both cases it has been supportive of the independence forces. Turkey sought to broker a cease fire in Syria and, upon its failure, has been a vigorous opponent of the Assad regime, housing Syrian opposition forces on Turkish territory and collaborating with Saudi Arabia to arm them.

Simultaneously, Turkey continues to deal with the quarter-century-long Kurdish insurrection and the unresolved political resolution of both the widely acknowledged Armenian genocide of 1915–1916 and the Greek–Turkish Cyprus dispute. It keeps a wary eye on signs of Russian expansionism in the Caucasus and Black Sea areas, and takes a cautious but not confrontational approach to Iran. Moreover, Istanbul's ongoing frustration at failure to gain entrance into the European Union (EU) is a major domestic economic and political issue.

Turkey has long fielded a modern military force with more than 500,000 troops, second only to the U.S. in NATO. It deploys a modern air force, a growing naval capability, excellent intelligence services, and houses NATO nuclear weapons at Incirlik, a Turkish air base that fields both Turkish and U.S. combat aircraft.

The impetus behind Turkey's growing independent foreign policy are the ambitions and attitudes of Prime Minister Recep Erdogan and the Justice and Development Party (AKP) that has been in power since 2002. Erdogan and the AKP have implemented modern economic reforms, first specified by an earlier International Monetary Fund agreement, that have hugely benefitted the Turkish economy while

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[1] R. Kozloski, "The Information Domain as an Element of National Power," *Strategic Insights*, **VIII**(1).

simultaneously eroding elements of the secular state established by Kemal Ataturk in 1923. In the process, Erdogan's government has made the Army clearly subservient to the political ruling class, almost for the first time in modern Turkish history.

The 100th anniversary of the establishment of the modern state, in 2023, is a significant milestone for Turkey, and many plans are aimed at achieving important goals by that time. It is in this context that we view Turkey's science and engineering developments and assess its movement toward strategic latency.

Has Turkey adopted strategic latency—the development of technologies positioned to provide notable military or economic advantage but not fully tapped—by accident or by design? Turkey has clearly established an aggressive push into S&T development as part of the nearly universal pursuit of an educated workforce and industrial base able to capture a share of the high-value-added jobs in today's globalized economy. But are its motivations also based on political–military calculations? This paper addresses the development of Turkish S&T capabilities in several areas. However, the analysis focuses on the drive toward a nuclear energy capability, as a precursor to a weapons capability, using this lens to examine S&T development.

The Political–Energy Context

Turkey has been seeking to acquire a nuclear energy capability for electric power generation for over 50 years, so far without success. Failure to attain nuclear energy is attributable to several factors. Economic conditions have been an obstacle. Dependence on unwilling nuclear power technology partners has also caused delays. Major nuclear controversies in Iraq, Iran, Pakistan, and elsewhere may have also helped to dampen enthusiasm for nuclear power in Turkey.

During most of this time, Turkey has been a member of the Nuclear Nonproliferation Treaty (NPT) regime, in addition to being a NATO ally. Energy needs have been a significant driver of this goal. In 2008, nearly 50 percent of the electricity in Turkey was generated from natural gas. Sixty percent of this gas came from Russia, and a significant portion of the remainder came from Iran, a situation that has made Turkey particularly sensitive to supply shocks. Nuclear power is viewed as a way to reduce reliance on outside energy sources.[2]

Perhaps the most salient feature in the Turkish case is the high degree of volatility in domestic politics during the last 50 years. Turkey has experienced four military coups in this period, and the discovery of potential plotting for a fifth coup in 2003 had ramifications for the political–military relationship that continue to this day. Erdogan's AKP has provided a decade of relative political stability and has seemingly consolidated control over a military bureaucracy that had previously been a cornerstone of Turkish decision making, although serious corruption charges against the government threatened political stability in late 2013.

Turkey reached agreement with the U.S. for peaceful nuclear cooperation in 2008 under agreed nonproliferation conditions and controls (a so-called "123 agreement" named after Section 123 of the U.S. Atomic Energy Act). Ankara then reached agreement with the U.S. to build a nuclear power plant.[3] Turkey signed a similar agreement with Russia in 2010 and a formal agreement with Japan in 2013 to build a second plant in Sinop.[4] These latter two efforts have survived the Fukushima catastrophe. As Turkey

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[2] Sebnem Udum, "Turkey's Nuclear Comeback," *The Nonproliferation Review* **17**(2), 365–377.

[3] U.S.–Turkey Agreement for Peaceful Nuclear Cooperation (123 Agreement), http://turkey.usembassy.gov/statement_060208.html.

[4] See "Turkey and Japan Sign Formal Agreement to Build Second Nuclear Plant in Sinop," Anadolu Agency, November 4, 2013. The first unit of the Sinop plant is scheduled to be active by 2023, with the last unit planned to be on line by 2028.

approaches its 100-year anniversary, the successes and failures of progress toward a nuclear capability figure prominently on the agenda, and the drive is still very much alive.

Turkish S&T under the AKP has experienced significant growth across several S&T sectors, fueled by substantial economic strengthening coupled with political stability. Prime Minister Erdogan has been able to leverage these conditions toward establishment of a sustainable domestic base of S&T expertise through the Supreme Council of Science and Technology (BTYK) and its secretariat, the Scientific and Technology Research Council of Turkey (TUBITAK).

In the past, development assistance played a larger role in terms of funds available to support S&T. In addition to multilateral and bilateral support, Turkey has benefited from its expanding participation in the EU Framework Programmes 4, 5, 6, and 7, despite not being an member. In addition, recent economic growth in the private sector has shifted considerable research to areas that do not fall directly under national or international research programs.

The expansion of the S&T base in Turkey is, therefore, both a result of and a driver for economic growth. Continued development of nuclear expertise, as well as the mastery of several supporting but potentially leapfrogging technologies, combined with the realization of a domestic nuclear power industry and several emerging security concerns, might all converge to propel a major leap up the strategic latency ladder. Turkey might stand to lose a great deal by pursuing an overt nuclear weapons program, but the calculation to move closer to the outer threshold of latency may prove optimal in the near future.

The Turkish government has issued several plans articulating Turkey's S&T approach. A recent study, "Vision 2023,"[5] reveals both the scope and range of the plans and the key 100-year anniversary milestones. While Turkey does not call for a return to empire status, the country appears to be on the rise to greatness, a central component of which is the development of a strong S&T base. Latency is clearly on the rise.

Nuclear Energy Development

Turkey's attempts to exploit nuclear energy have occurred in phases. The first began in the wake of President Eisenhower's "Atoms for Peace" speech before the UN in 1953 with the establishment of the Turkish Atomic Energy Commission (TAEC) 1956. In 1961, Turkey formed the Cekmece Nuclear Research and Training Center, installing a 1-megawatt-thermal (MWth) research reactor, TR-1, a year later. In 1966, the Ankara Nuclear Research and Training Center was established as the second major branch of TAEC for fundamental and applied research. Plans for the first 300–400-MW nuclear power plant (NPP) using natural uranium began in 1967, with the goal of becoming operational by 1977.[6] However, domestic economic and political developments led to the cancellation of that program in 1970.[7]

In a second attempt to develop nuclear capacity, the Turkish Electricity Administration (TEK) carried out studies for an 80-MW prototype plant between 1972 and 1974. Plans for this small reactor were canceled in 1974 because of fears that it could delay a larger, planned 600-MWe NPP project.[8] Site selection studies continued at Akkuyu Bay, which was chosen for its seismic stability, and a license was issued in 1976.

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[5] http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/arsiv/Special_Brief_Guncel19_Web.pdf.

[6] Mustafa Kibaroglu, "Turkey's Quest for Peaceful Nuclear Power," *Nonproliferation Review* **4**(3), 33–44, http://kms1.isn.ethz.ch/serviceengine/Files/ISN/114457/ichaptersection_singledocument/7bbd109d-7d93-49e2-8f8d-6bb46f1bc971/en/Article03-Kibaroglu.pdf.

[7] Udum, "Turkey's Nuclear Comeback. . . ."

[8] Erkan Erdogdu, "Nuclear Power in Open Energy Markets: A Case Study of Turkey," Energy Policy, 35(5), 3061–3073, http://ideas.repec.org/a/eee/enepol/v35y2007i5p3061-3073.html.

These plans did not come to fruition because of the military coup in 1980 and the withdrawal of loan guarantees by the Swedish government. [9]

In 1979, the 250-kilowatt-thermal Triga Mark II research reactor started operations at Istanbul Technical University. In 1981 the TR-1 research reactor, shut down in 1977, was replaced by the TR-2, a 5-MWth pool-type research reactor.[10]

This phase included a site selection survey for a second NPP near Sinop. However, this initiative ran into trouble in 1981 as the U.S. expressed its concerns regarding illicit Turkish cooperation with Pakistan on strategic materials with nuclear implications.[11]

Between 1983 and 1985 efforts were made to reinvigorate the drive toward an operational NPP, with Canadian, West German, and U.S. firms expressing interest in providing technology. However, seismic issues and disputes over financing conditions drove providers away. Atomic Energy of Canada, Ltd., was the last company to withdraw. Some in Turkish diplomatic circles perceived the Canadian withdrawal as a response to pressure from Western countries stemming from fears that Turkey could build a bomb based on Canada Deuterium Uranium, or CANDU, technology.[12] After the Chernobyl accident of 1986, Turkey abolished its Nuclear Power Plants Department and put further nuclear energy development on hold.[13]

Two years later, a 15-year nuclear cooperation deal with Argentina was signed involving significant technical transfer from Argentina to Turkey, including front-end nuclear fuel cycle research and development (R&D). Turkey was particularly interested in the 380-MWe Argos pressurized water reactor design unveiled a year earlier in Argentina, and Argentina agreed to help study the feasibility of a site in Turkey. As part of the deal, Turkish scientists would go to Argentina's Bariloche Nuclear Center for training, and the two countries were to cooperate on uranium mining, nuclear fuel plants, industrial production of isotopes, and safety requirements.

In 1990, the Turkish Atomic Energy Authority and Argentina agreed to form a joint firm to develop Argentina's modular, low-power CAREM-25 reactor, with plans to build one in each country. Turkey would provide most of the financing, and Argentina would provide the technology. The stated hope of Argentinian officials was that, if the smaller reactor project was successful, Turkey would subsequently buy a 380-MWe Argos pressurized water reactor. However, the small size of the CAREM-25 reactor made it unsuitable for electricity generation but capable of plutonium production, and the project generated a great deal of suspicion about Turkish intentions. Already concerned over the appointment of Adolfo Saracho, former head of Argentina's nuclear energy commission, as the Ambassador to Ankara in the early 1980s, the U.S., Soviet Union, and Germany grew concerned that Turkey's acquisition of nuclear technology could be transferred to Pakistan and was therefore dangerous. The agreement was canceled by Turkey's unilateral decision amid fears that pursuing the project could jeopardize Turkey's future ambitions for the larger-scale reactors that the country needed.[14]

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[9] Kibaroglu, "Turkey's Quest for Peaceful Nuclear Power. . . ."

[10] Ibid. and Henri J. Barkey, "Turkey's Perspectives on Nuclear Weapons and Disarmament," in *Unlocking the Road to Zero: Perspectives of Advanced Nuclear Nations* (Washington, D.C.: Stimson Center, 2009), http://www.stimson.org/images/uploads/research-pdfs/BJT_Print_Final.pdf.

[11] Kibaroglu,"Turkey's Quest for Peaceful Nuclear Power. . . ."

[12] Ibid.

[13] Udum, "Turkey's Nuclear Comeback…"

[14] Kibaroglu, "Turkey's Quest for Peaceful Nuclear Power…"

The third phase of nuclear development in the 1990s started with a warning from the Ministry of Energy and Natural Resources of an impending energy crisis. Subsequently, the High Council of Science and Technology identified nuclear energy as the third highest priority for the country, and a NPP project was included in its investment program.[15] But fears of the Pakistani connection lingered and were joined by concerns over Turkish relations with the Turkic republics in Central Asia and the Caucasus, some of which had nuclear installations left behind by the former Soviet Union (FSU). U.S. Senator John Glenn cited the failure of the Glenn and Symington amendments to the Foreign Assistance Act to stop aid to Turkey based on its assistance to Pakistan. Similarly, the Greek foreign ministry expressed concern that Turkey might try to recruit materials and know-how from the Muslim republics of the FSU.

Under this climate, in 1995, Turkey announced the issuance of requests for bids on the site at seismically stable Akkuyu Bay. However, soon a new pro-Islamic government came to power in Turkey, leading to reluctance and hesitation among the bidders.[16] In 1997, three bids were received for NPP contracts, from Atomic Energy Canada, Ltd. (Canada), Nuclear Power International (French Framatome and German Siemens), and a Westinghouse (U.S.)/ Mitsubishi (Japan) partnership. They were ultimately postponed and canceled.[17] By July 2000 the entire nuclear energy program was postponed indefinitely until economic conditions improved.[18] The government could not afford the estimated $3–4 billion needed for construction.[19]

Despite these failures to build a generating facility, Turkey's nuclear expertise has grown, especially with regard to recovery of uranium. A successful pilot plant started to operate in 1986 with 1.5 tons of uranium concentrate imported from Canada. Turkey's natural uranium and thorium deposits are reported to be 8,400 tons and 380,000 tons, respectively. The uranium deposits could reportedly constitute the basis for fueling three 650-MWe pressurized heavy water reactors.[20]

In 2000, proliferation concerns surfaced regarding Turkish nuclear-related trade with Iran, holding up an energy cooperation agreement with the U.S. By 2008, however, sufficient confidence had been restored to allow the U.S.–Turkey agreement to be brought into force.[21] Nevertheless, this agreement is relevant only if there is bilateral nuclear commerce, and so far Russia has proven to be a much more engaged partner with Turkey than the U. S.[22]

After the AKP came to power in 2002, the nuclear program was revived by the Ministry of Energy and Natural Resources, with the government announcing that it wanted to have 5,000 MWs of nuclear power in operation by 2012.[23] As noted earlier, recent partnerships with Russia and Japan appear to have endured

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[15] Erdogdu, "Nuclear Power in Open Energy Markets…"

[16] Kibaroglu, "Turkey's Quest for Peaceful Nuclear Power. . . ."

[17] David H. Martin, *The CANDU Syndrome: Canada's Bid to Export Nuclear Reactors to Turkey* (Ottawa, Canada: Campaign for Nuclear Phaseout, 1997), http://www.ccnr.org/turkey_syndrome.html.

[18] Erdogdu, "Nuclear Power in Open Energy Markets . . . ."

[19] Martin, The CANDU Syndrome. . . .

[20] Kibaroglu, "Turkey's Quest for Peaceful Nuclear Power. . . ."

[21] Udum, "Turkey's Nuclear Comeback. . . ."

[22] Jessica C. Varnum, "Turkey in Transition: Toward or Away from Nuclear Weapons?," in W. C. Potter, ed., *Forecasting Nuclear Proliferation in the 21st Century*, Volume 2, A Comparative Perspective (Stanford, CA: Stanford University Press, 2010).

[23] Erdogdu, "Nuclear Power in Open Energy Markets . . . ."

the global nuclear backlash from the Fukushima disaster. The impact on the nuclear energy program of the 7.2-earthquake on October 23, 2011, and the 5.7 earthquake on November 9, 2011, in eastern Turkey, which occurred after Fukushima, are still not fully understood.

The Turkish Security Environment

Turkey signed the NPT in 1969 but did not ratify it until 1980. Although this delay has caused some to question the Turkish commitment to the NPT, significant domestic turmoil in this period brought the country to the brink of civil war, leaving the Grand National Assembly little time to focus attention on the ratification of the treaty. Turkey has been a vocal supporter of nonproliferation ever since, assuming full member status in the Conference on Disarmament in Geneva and promoting discussion of the Strategic Arms Reduction Treaty process, conclusion of the Comprehensive Test Ban Treaty, and a Fissile Material Cut-off Treaty.[24] Turkey joined the Nuclear Suppliers Group in 2000, and in 2001 it acceded to the International Atomic Energy Agency's Additional Protocol.

The delayed NPT ratification has not been the only source of concern regarding Turkey and nuclear proliferation. In 1981, the U.S. expressed concerns about shipments of inverters to Pakistan by a Turkish textile firm. In 1990, the 25-MW reactor planned in partnership with Argentina drew a great deal of suspicion as it was deemed too small for electricity and too big for research, but perfectly suitable for plutonium production. Furthermore, the possibility of transfer of the complete nuclear fuel cycle to Turkey raised serious concerns in the U.S., Greece, Israel, and India.[25]

In 2010 Turkey issued a joint declaration with Iran and Brazil regarding the impasse on the Iranian nuclear program, timed to diffuse the impact of the UN Security Council sanctions on Iran. On May 17, 2010, Erdogan, Iranian President Mahmoud Ahmadinejad, and Brazilian President "Lula" da Silva announced that Iran would send 1,200 kilograms of its low-enriched uranium to Turkey in a single shipment and receive fuel rods for its nuclear research reactor from the Vienna Group within a year. The day after the agreement, the Obama administration announced new sanctions on Iran from the Security Council, and France openly criticized the Turkish agreement. Other areas of tension include Turkey's policy toward Israel, especially after the Gaza flotilla incident, engagement with Hamas, relations with Syria in the wake of the intensified civil war, a complex role in Iraq, disputes over the election of the new Secretary General of NATO, cooperation in the Black Sea, and missile defense plans.[26]

Viewed from the Turkish perspective, there have been several causes for concern regarding the NPT. The gravest center on the failure of the NPT regime to prevent the development of weapons programs in North Korea, Iran, and Syria, and the diminished credibility of security guarantees by both NATO and the U.S.

In 1946, Turkey had few options other than Western alignment. The Soviet Union had troops stationed on Turkey's Caucasus and Balkan borders and military advisers in Iraq and Syria. The surrounding economies were some of the least dynamic and most closed in the world, and the only opening to prosperity was through Europe.[27] Turkey, however, was in a position to provide vital support for the West by blocking

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[24] Mustafa Kibaroglu, "Turkey," in H. Muller, ed., *Europe and Nuclear Disarmament: Debates and Political Attitudes in 16 European Countries* (Brussels: European Interuniversity Press, 1998).

[25] Ibid.

[26] Sinan Ulgen, *A Place in the Sun or Fifteen Minutes of Fame? Understanding Turkey's New Foreign Policy* (Brussels: Carnegie Endowment for International Peace, 2010), http://www.carnegieendowment.org/files/turkey_new_foreign_policy.pdf.

[27] *The Geopolitics of Turkey: Searching for More* (Austin, TX: STRATFOR, 2010).

Soviet advances into Western Europe and providing bases for long-range bombers to contain Soviet ambitions.[28]

Since then, Turkish perceptions of security threats have shifted away from Cold War calculations. Past concerns over Soviet claims to the Turkish Straits strengthened the desire to have NATO's nuclear weapons in their country.[29] Then, with the collapse of the Soviet Union at the end of 1991, the number of states neighboring Turkey doubled overnight. Conflicts between Azerbaijan and Armenia as well as the fighting in the territory of former Yugoslavia, left Turkey surrounded by intra- and interstate conflict in the Balkans, the Middle East, and the Caucasus. Concern over Turkey's own unity and state sovereignty began to attract more attention from internal political and security elites.[30]

As a recipient of Western security guarantees during the Cold War, Turkey was under great pressure to remain aligned with the West. However, the declining threat perception has challenged this asymmetric relationship and significantly reduced the West's leverage over Turkey's policy choices, leaving Turkey with many new options to promote its influence. In 2005 Turkish President Ahmet Necdet Sezer visited Damascus. Despite criticism from the U.S., this gesture was helpful in gaining Turkey a significant role in brokering peace talks between Israel and Syria in 2007. Turkey removed Iran and Syria from its formal list of security threats in 2010.[31] Moreover, Turkey strived diplomatically to eliminate references to Iran and Syria as specific threats following the Lisbon NATO summit in 2010.

Ankara's current security concerns, besides Kurdish separatism and the Kurdistan Workers' Party (PKK), are primarily internal with foreign linkages. Iraqi Kurds have enjoyed a quasi-independent state since the 1991 crisis with Iraq over Kuwait, and they gained official recognition within Iraq as a federal Iraqi state in the aftermath of the 2003 Iraq War.[32] Turkish fears of northern Iraq serving as a stepping stone to the establishment of a Kurdistan have been bolstered by Kurdish control over and direct contracting for the oil resources of Kirkuk. Lack of U.S. and NATO support in combating the PKK has fostered criticism and reconsideration of Turkey's relationship with the West. The Kurdish population covers large parts of territory in Iran, Syria, and Turkey, bringing the three closer together in their opposition. As the U.S. withdrew its forces in Iraq, many saw Iran as the most likely to fill the power vacuum. Iran's potential influence in a post-U.S. Iraq is an added incentive for Turkey to continue its engagement with Iran.

Prior to the Persian Gulf War in 1991, U.S.–Turkish relations had suffered two major periods of distrust, both involving Cyprus. Other more recent irritants include the Armenian Genocide Resolution, which passed a House committee in 2007. Passage of a similar resolution in France led to Turkey halting all military cooperation with France, and the U.S. has been warned of similar repercussions.[33]

Turkish concerns about the credibility of U.S. security guarantees date back 50 years. In the aftermath of the 1957 NATO summit in Paris, the decision was made to place intermediate-range Jupiter missiles in

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[28] Leon Fuerth, "Turkey: Nuclear Choices amongst Dangerous Neighbors," in K. M. Campbell, R. J. Einhorn, and M. Reiss, eds., *The Nuclear Tipping Point: Why States Reconsider Their Nuclear Choices* (Washington, D.C.: Brookings Institution Press, 2004).

[29] Kibaroglu, "Turkey," in H. Muller. . . .

[30] Ibid.

[31] Ulgen, "A Place in the Sun or Fifteen Minutes of Fame?. . . .

[32] Barkey, "Turkey's Perspectives on Nuclear Weapons and Disarmament. . . ."; and "Chain Reaction: Avoiding a Nuclear Arms Race in the Middle East," Report to the Committee on Foreign Relations, U. S. Senate, February 2008, http://www.fas.org/irp/congress/2008_rpt/chain.pdf.

[33] Ibid.

Turkey.[34] Deployed in 1961, they were withdrawn in 1963 as part of the resolution of the Cuban missile crisis.[35] (The failure of the U.S. to consult Turkish leaders on the withdrawal decision undermined for Ankara the credibility of U.S. security guarantees.) Since then only nuclear bombs, not missiles, have been deployed in Turkey, all of them now in one location at Incirlik. The Turkish Air Force has no operational link to any of them, despite calls from the beginning for pre-delegation authority from Turkey.[36] Although these weapons add credibility to Western guarantees, the weapons have drawn criticism from Turkey's neighbors in the Middle East such as Iran and Syria who perceive the weapons as being directed against them, and Egypt who sees them as a symbol of Western imperialism and an obstacle to a Nuclear Weapons Free Zone in the Middle East. Some in Iran have even gone so far as to argue that these weapons make Turkey a nuclear weapons state, in an attempt to justify continued Iranian investment in their own nuclear program. Other countries hosting weapons, such as Belgium, Germany, and the Netherlands, have expressed an interest not to continue to do so, especially in the wake of the "global zero" movement initiated by President Obama. If these countries were to discontinue hosting weapons, only Italy and Turkey would remain as NATO nuclear hosts.[37]

It is self-evident that Turkey resides in a highly unstable region with complex bilateral relations with Egypt, Syria, Iraq, Iran, and Pakistan. The details of these relations are beyond the scope of this paper, but we have one overall conclusion: the turmoil within each state and across the region is pronounced and it strengthens Turkish incentives to provide its own advanced military capabilities based on advanced S&T. Such efforts also serve to promote Turkey's ambitions as a major regional power in the Islamic world.

Changes under the Justice and Development Party

After the AKP came to power, it succeeded in mobilizing manpower in the state bureaucracy to transform its Kemalist nature, by leveraging a coalition of intellectuals, professors, judges, prosecutors, police, businessmen, and journalists. This capacity was augmented by new sources of financing from the new Anatolian middle class, ending the monopoly of state-centric capital.

By 2007, the AKP began to turn the tables on the military establishment. Seeking to challenge the military's grip on power, the AKP launched two investigations regarding 2007 and 2010 conspiracies to destabilize the government. Both investigations resulted in many arrests of prominent military leaders and caused many others to resign in protest, although there were widespread claims that the cases were fraudulent and rested on superficial and fabricated evidence. The AKP has also significantly increased civilian control over the National Security Council, with the number of military officers reduced from five to one, leaving the Chief of Staff as the sole remaining officer. In addition, new legislation required that the secretary general be a civilian, a position that in the past was held by an officer. In 2010, the AKP announced that its ambassador to Lebanon, Serdar Kilic, would be the new secretary general of the MGK,[38] although Kilic has most recently been appointed Turkey's ambassador to the U.S.

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[34] Mustafa Kibaroglu, "Reassessing the Role of U.S. Nuclear Weapons in Turkey," *Arms Control Today* **40**(5).

[35] Fuerth, "Turkey: Nuclear Choices amongst Dangerous Neighbors. . . ." A senior Turkish diplomat informed one of the chapter authors in April 2011 that the removal of these missiles remains a hallmark of distrust by Turkey of U.S. security commitments.

[36] Ibid.

[37] Kibaroglu, "Reassessing the Role of U.S. Nuclear Weapons in Turkey. . . ."

[38] "Government Names Young Diplomat New MGK Secretary-General," Today's Zaman, January 26, 2010, http://todayszaman.com/tz-web/news-199681-100-govt-names-young-diplomat-new-mgk-secretary-general.html.

The effects of this massive shift in domestic political power, away from the military and toward the AKP, has had significant effects on both diplomatic and military aspects of national power. For the first time in Turkish history, the military seems to have been brought to heel by the political establishment.

One temporary foreign policy pivot relates to Iran. Turkey's secular security establishment was alarmed by the 1979 Iranian Islamic Revolution, and the Turkish authorities accused Iran of fomenting domestic unrest. By contrast, the AKP, and the general Turkish public, initially had a much more benign view of Iran, and bilateral relations have improved substantially since 1979.[39] However, in recent years, it has been clear that Turkish nationalists view Iran as a regional rival. Turkish Islamists, moreover, do not support Iran's nuclear weapons program, an asymmetry brought to the Turkey–Iran relationship that is much more important than having an "Islamic" bomb against a "Jewish" bomb.

For the national security elite, which is the most vocal with concerns about Iran's programs, a major theme is loss of the relative power of Turkey in the region to Iran. Other themes include Iran's ideological leadership and connections to terrorism. Since 2011, with the intensification of the Syrian conflict, Turkey and Iran have been on opposite sides: Iran the chief supporter of the Assad regime, and Turkey allied with Saudi Arabia as a major opponent. Turkey–Iran relations have soured in the process.

There appears to be broad domestic support for Turkey's growth of nuclear power. Opinions observed in internet sites, blogs, and chat rooms suggest that Turks do not anticipate that Iran would target Turkey, a fellow Muslim nation, especially because Israel is the main focus. These opinions also convey public support for the possession of nuclear weapons, for the same reasons expressed by other countries in the past.[40] However, the growing secular conflict throughout the region between Sunnis and Shias has moved Turkey closer diplomatically to Saudi Arabia and other Sunni Gulf states. Turkey is increasingly concerned about Iran's enhanced influence in the Middle East, especially if Iran were to acquire nuclear weapons of its own.

A Modernizing Economy

An important theme of Turkey's modernization is the shift of the economic power base away from the Marmara Sea region and toward the Anatolian east, a phenomenon some have labeled the rise of the "Anatolian Tigers." The political and economic consequences of the spread of S&T development to eastern Turkey, which have previously received much less attention, highlight the second-order political and economic effects of strategic latency.

Since the collapse of the Soviet Union, Turkey has become the center of a new economic space. Several trends point to Turkey's emergence as a significant trading state. In 1980, Turkey's exports were $3 billion and, in the same year, it abandoned an import substitution strategy that protected domestic industry behind high tariffs in favor of an export oriented growth strategy. By 2008, exports were $132 billion. About 250 industrialized zones have grown in Anatolia. Cell phone users have grown from a base of almost zero in the 1990s to 64 million in 2008.

In 2004, Turkey was the world's 16th largest economy with a gross national product of $269 billion, or roughly $3,750 per capita, and its growth rate was 8.9 percent. In the years since 2004, gross domestic product (GDP) has increased from $192 to $640 billion in 2009, with per capita income nearly tripling to $9,000. Although 29 percent of the labor force is employed in agriculture, the economy has experienced a significant shift to the industrial and service sectors. Energy demand has also been growing steadily, with

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[39] Barkey, "Turkey's Perspectives on Nuclear Weapons and Disarmament. . . ."

[40] Mustafa Kibaroglu and B. Caglar, "Implications of a Nuclear Iran for Turkey," *Middle East Policy* **15**(4), 59–80, http://www.mustafakibaroglu.com/sitebuildercontent/sitebuilderfiles/Kibaroglu-Caglar-MEP-04December2008.pdf.

an electrical consumption growth rate of 8.3 percent per year from 1973 to 2002, making Turkey one of the fastest growing energy markets in the world.[41] However, the recent global economic crisis has taken its toll on Turkey, stopping growth dead in its tracks.[42]

Exports have grown from $28 billion in 2000 to $132 billion in 2008, while foreign direct investment grew from $800 million in 1999 to $22 billion in 2007. This growth was highest with Turkey's immediate neighbors, rising from $18 billion in 2000 to $53 billion in 2009, expanding the relative share of Turkey's exports to its neighbors from 16 to 20 percent. The largest trade deficits are with Russia, and Iran, two countries with which Turkey would like to expand its exports. Foreign direct investment from the Near and Middle East increased 16 times from $918 million to $6.7 billion, but the EU still dominates foreign investment at $47 billion from 2005 to 2010.[43]

As a major connecting hub between Europe and Asia, Turkey is a candidate to be an "energy corridor" connecting the rich oil and natural gas resources of Asia, the Middle East, and the Caspian Sea region to the consumer markets in Europe. In 2009, Turkey signed an agreement with six other countries to build the TransAnatolian Pipeline natural gas pipeline from the Caucasus and Central Asia, through Turkey to Europe. Completing this project will require a great deal of agility with both the West and Russia, but the project has raised the importance of Turkey to the energy consumers of the EU.[44]

Shifting Foreign Policy

Turkey has instituted a foreign policy of "zero problems with neighbors" and "strategic depth"[45] with three key priorities defining it: re-conceptualizing Turkey's identity and international role, reducing the security component of its foreign relations, and increasing its strength as a trading state. This new policy challenged traditional conceptions of Turkey as a state on the European periphery and rooted in the West. Whereas previous political leadership sought to distance itself from Middle East politics, the current political elite sees Turkey as an emerging leader in the Islamic world and its involvement in the Middle East as its manifest destiny. The AKP has dispensed with European parliaments in favor of the promise and admiration to be gained by dealing with the governments of the Middle East.

Although Davotoglu does not emphasize the theme of economic interdependence in his pivotal book *Strategic Depth*, he does suggest elsewhere that economic interdependence may be a means to create "order" in the Middle East.[46] Turkey's recent economic success has given it much more visibility in the world of international aid. In 2008, it gave $780 million to 98 countries. Afghanistan received almost 45 percent of Turkey's aid, with the next 16 countries from the Balkans or Turkey's immediate neighborhood (except for Sudan and Ethiopia).[47] More recent figures suggest Turkey's aid at $2.5 billion, placing Turkey among the top three countries providing humanitarian aid.

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[41] Erdogdu, "Nuclear Power in Open Energy Markets…"

[42] M. Abramowitz and Henri Barkey, "Turkey's Transformers," *Foreign Affairs*, November 2009, http://www.foreignaffairs.com/articles/65464/morton-abramowitz-and-henri-j-barkey/turkeys-transformers.

[43] Erdogdu, "Nuclear Power in Open Energy Markets. . . ."

[44] Ibid.

[45] Udum, "Turkey's Nuclear Comeback. . . ."

[46] Davotoglu's book is discussed in Ulgen, "A Place in the Sun or Fifteen Minutes of Fame?. . . .

[47] Ibid.

Until about 2011, Turkey's new foreign policy had began to succeed. Relations with Arab neighbors improved greatly, including with Syria (until recently), Iraq, and Lebanon. For example, in Iraq, an old view of hard-core security concerns focused on limiting the influence of Kurdish leaders has given way to a new view of soft power seeking to increase Turkish influence over Iraq's economic and political future.

In the fourth "perception of Turkey in the Middle East" research, a 2012 poll of 2,800 individuals in 16 countries found that despite the turmoil in the region and reactions from Syria, Iran, and Iraq, Turkey is still seen positively. Sixty-nine percent have a positive opinion of Turkey, making it the most popular among 18 countries in and outside the region.[48] Turkey's mediation portfolio has expanded to include larger roles in Afghanistan and Pakistan, Bosnia and Serbia, Georgia and Abkhazia, and Israel and Palestine. The mediation role was complemented by several multilateral initiatives, including a seat on the UN Security Council from 2009 to 2010, the Outreach to Africa program in 2005, and the secretary general position in the Organization of Islamic States.[49] However, the Arab Spring has led to a challenging phase in Turkish foreign policy as relations with Syria, Egypt, Iran, Iraq and Lebanon have all become much more difficult.

Turkey's increasing involvement in Gaza has continued to degrade relations with Israel, which hit a low point in the aftermath of the 2010 flotilla incident in which Israeli forces killed nine Turkish citizens.[50] Given the leadership vacuum in the Arab Muslim world, Erdogan discovered that by taking a hard line against Israel, Turkey could increase its popularity in the Arab street and in the Arab marketplace. Thanks to his vocal rhetoric against Israel, Erdogan, although not an Arab himself, became among the most popular leaders in the Arab world.[51]

Important shifts in Turkish public opinion have resulted from these events. In 2008, just one-third of the public wanted their country to join the EU, down from 80 percent in 2002. Furthermore, self-identification as a Muslim was up 10 percent from 2002 to 2007, and over 50 percent of those surveyed described themselves as Islamist.[52] But these gains have stalled as the Arab Spring has brought enormous conflict and tension throughout the region.

In its tilt eastward, however tentative, Turkey has not abandoned its efforts to integrate further with Europe, resulting in a net expansion of Turkey's global influence. For example, as a nonmember of the EU, Turkey does not have access to EU structural funds. However, Turkey has made important gains in S&T collaboration with the EU Framework development programs. The Turkish Research Area, for example, was inspired by the European Research Area.

Although the drive for full EU membership has stalled, Turkey derives some benefits not connected to the realization of this goal. In fact, given the current economic crisis in the EU, Turkey's intermediate stage of integration with the EU could be considered optimal. Participation in the Framework programs is a perfect example. Increased levels of participation have benefited Turkey's S&T community, expanded its network or partners, and bolstered its own domestic S&T development activities. The Sixth Framework

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[48] Mensur Akgun and Sabiha Senyucel Gundogar, "The Perception of Turkey in the Middle East 2012," Turkish Economic and Social Studies Foundation, Istanbul, Turkey, 2012.

[49] Ulgen, "A Place in the Sun. . . . ."

[50] Ibid.

[51] Thomas Friedman, "Letter from Istanbul," *New York Times*, June 16, 2010, http://www.nytimes.com/2010/06/16/opinion/16friedman.html.

[52] Soner Cagaptay, "Is Turkey Leaving the West?" *Foreign Affairs*, October 26, 2009, http://www.foreignaffairs.com/articles/65661/soner-cagaptay/is-turkey-leaving-the-west.

Programme (FP6) was the first in which Turkey participated as an EU associate country. The three major effects were increased awareness of research and innovation among stakeholders, better coordination mechanisms for public–private partnerships, and favorable legislation for researchers. An upward trend in acceptance of projects with Turkish partners influenced the decision to participate in FP7.

S&T Foresight

Between 2002 and 2004, TUBITAK (The Scientific and Technological Research Council of Turkey) carried out an extensive technology foresight study to examine alternative futures and set R&D priorities as the country moves toward its centennial. The resulting document, "Vision 2023," demonstrated the government's serious intent to put their country on the forefront of S&T as part of a broader effort to assert leadership in the region and beyond. One outcome of the study was the establishment of the European-inspired Turkish Research Area in 2004 as a platform for collaboration between the private and public sectors and NGOs.

Turkey has identified several priority fields of research, including nanotechnology, information and communications technology (ICT), and design technologies. Further development of these technologies will allow Turkey to augment its competitive superiority in industrial production with high-value-added, knowledge-intensive products. Turkey would like to become a global design and production center, active in development of space and defense technology, advanced manufacturing, and materials science. Other benefits of R&D will include better quality of life through improved infrastructure, a smoother transition to an information society, and more sustainable development with regard to energy, the environment and natural resources.

The Turkish Research Area has accelerated Turkish S&T growth across its development goals. Investment in S&T has increased gross domestic expenditures on research and development from $2 to $9 billion in purchasing power parities**,** almost quadruple the averages for countries in the Organization for Economic Cooperation and Development and the EU27.[53] The business sector outperformed higher education in 2008 for the first time for performing R&D projects, and it surpassed government in 2005 as the leading sector funding R&D. The number of full-time-equivalent researchers was nearly 58,000 in 2008, requiring the previous target of 40,000 by 2010 to be revised upward to 150,000 by 2013. Scientific publications and patents increased nearly 305 percent between 1998 and 2007, making Turkey one of the most dynamic sizable countries leading the "catch up" process. Turkey was the only exception in the cluster of Brazil, Russia, India, China (BRICs)and South Korea whose share in world publications exceeded its share of PhD degrees awarded.

TUBITAK is the main instrument of research policy in the public sector. TUBITAK's main programs are managed by its Research Support Programs Directorate, which increased funding ten-fold between 2004 and 2009. TUBITAK is also active in the private sector via its grant-making Technology and Innovation Support Program Directorate (TUBITAK-TEYDEB). TUBITAK-TEYDEB disburses the greatest amount of funds. Procurement is not used to stimulate private sector R&D, but additional funding is made available to projects in ICT, bio and genetic technology, materials technology, nanotechnology, design technology, advanced production processes, and energy and environment technologies.

Turkey's space technologies research institute manages national and international research and consultancy projects, mainly in space technology. It also seeks to become a pioneer of united approaches in information technology and electronics research. The institute combines the capabilities of the public and private sectors as well as universities to produce information technology that improves the technological

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[53] "Science, Technology and Innovation in Turkey," TUBITAK, 2010, http://www.tubitak.gov.tr/tubitak_content_files/BTYPD/arsiv/STI_in_Turkey_2010.pdf.

base of national industries. It also participates in international projects and develops regulations, policies, and standards to guide the sector. The institute participates in many international research projects with partners such as NATO, EUREKA (an intergovernmental organization for market-driven industrial research and development), and the World Bank.

A complex network of almost 150 institutions of higher learning and more than 100 public research organizations, plus private research organizations and other support programs undergird Turkey's S&T efforts. Collectively, the extensive network of state-sponsored S&T institutions is advancing Turkey's technical capabilities and status as a rising power. Programs in computations and cybersecurity, nanotechnology, lasers/photonics, and additive manufacturing are under way with the aim of making Turkey a major S&T player. Details are provided in Appendix 1.

Trigger Events for Latency

This analysis has touched on several variables that help define different types of strategic latency. They can be used to explain Turkey's current status and a few potential outcomes for the future. Sticking to the lens of nuclear weapons, and the time frame of the "Vision 2023" document, let us consider the issue of latency.

Varnum offers seven categories of trigger events that could move Turkey to weaponize its technologies in the nuclear field: acquisition of nuclear weapons by another state; perceived abrogation of U.S. security guarantees, such as the removal of tactical nuclear weapons from Incirlik Air Force Base; conventional preemptive strike against Iranian nuclear facilities to which the Turkish public is adamantly opposed; vertical proliferation by existing nuclear weapons states such as Russia; nonnuclear regional security shocks that turn nonthreatening neighbors into security risks; leadership change, although unlikely, to an ultra-nationalist isolationist party such as the Nationalist Movement Party; and EU unequivocal refusal of full and equal membership.[54]

Varnum offers an estimate on the lag time required for Turkey to acquire nuclear weapons. Although Turkey has no known access to enriched uranium or separated plutonium, and no large-scale reactors to produce plutonium, the country's strong background in basic nuclear research and applications, and modest reserves of uranium have been described as "having everything for chicken soup, except the chicken." Hurdles in moving from baseline technology to weapons capabilities are often left out of proliferation calculations.

By some optimistic estimates, normal development requires 338 weeks and $190 million, while a crash course would require 260 weeks and $380 million or just 208 weeks for acquired or stolen highly enriched uranium.[55] These estimates fail to account for possible ineffective management practices. Covert development, although difficult for Turkey, does provide a shorter route. However, the disappearance of key technical personnel would likely be noticed, and it is not clear whether the scientific community would support the initiative. Outside assistance could provide acquisition of weapons overnight, although not a sustainable domestic program. In most circumstances, states are not interested in taking such risks unless the design and capability is robust.

Assuming that Turkey achieves the successful deployment of a nuclear power plant by 2015, by 2021 it could have enough plutonium in spent fuel for one or more devices. At this stage, however, licenses have not been issued and construction has not been initiated. Processing the plutonium would require either

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[54] Varnum, "Turkey in Transition. . . ."

[55] Robert Harney et al., "Anatomy of a Project to Produce a First Nuclear Weapon, *Science and Global Security* **14**, 163–182, http://www.nps.navy.mil/orfacpag/resumePages/papers/brownpa/BrownEtAlBriefAnatomy.pdf.

withdrawal from the NPT or hiding of reprocessing facilities, both of which are difficult but not impossible. Rumors in 2008 suggested that Turkey planned to enrich its own uranium, but this was denied by Turkish officials. Turkey's official position is that it has no plans for domestic uranium enrichment, but it does not want to forego a right that it considers inalienable under the NPT. Ultimately, Turkey's proliferation decision is likely to depend on the decision to invest in the capability to produce fissile material indigenously.

Singh and Way model state nuclear weapons proliferation as a continuum across four stages: no interest or effort whatsoever; exploration of the possibility of developing or acquiring weapons; substantial efforts to develop weapons; and the acquisition of weapon capability. Using this model, Turkey has not yet reached stage four, and its overt S&T policy and nuclear posture would suggest that it is not in stage three either. However, certain political voices in Turkey have called for the development of nuclear weapons. If we include NATO's estimated 90 tactical nuclear weapons stationed in-country at Incirlik Air Force Base,[56] Turkey might be viewed as in stage two. In their findings, Singh and Way discuss three categories of statistically significant correlates of proliferation: technical, external security, and domestic.

The technological determinist literature has argued that latent capacity is determined by economic prosperity, literacy levels, and scientific development. As it becomes cheaper and easier for a state to acquire weapons, the likelihood that the state will do so increases. The implication of this pessimistic view is that once a latent capacity is achieved, it is only a matter of time until nuclear weapons are acquired. However, although this view may be persuasive with some policy makers, it suffers from lack of empirical support and many counter examples of states that had the technical capacity to build weapons but refrained from moving forward with a weapons fabrication program. Singh and Way categorize this literature as identifying a necessary but insufficient condition for the pursuit of nuclear arms. Regarding technological determinants, Singh and Way found that the likelihood of proliferation rises sharply with economic growth at low levels of development but levels off and even declines at high levels after a threshold is reached.

External determinants affect the willingness rather than the ability of states to build nuclear weapons. In general, the two most important external security factors are the presence or absence of a security threat, and the security guarantee of a powerful alliance partner. Given a security threat, three plausible choices are to develop one's own nuclear ability, publicly refrain from such efforts to reassure potential rivals, or forge an alliance with a powerful partner.

Domestic determinants, like their external counterparts, also focus on state motivation instead of ability. Four factors identified as having influence regarding decisions of proliferation include democracy, liberal governments, an autonomous domestic elite, and symbolic/status motivation. Democracy can be stabilizing, although in periods of democratization, competing elites face incentives to stir up nationalism. Liberal governments are seen as less likely to proliferate than inward looking nationalists, because they are more interested in promoting economic prosperity opportunity to make money than the opportunity to build a bomb.[57] An autonomous domestic elite, more likely found in nondemocracies, has the freedom to use security concerns to promote their own parochial gain. Nuclear weapons can become normative symbols of modernity and legitimacy especially for states seeking validation as modern and powerful.

According to this model, Turkey has had a high predicted hazard rate for several years, leaving many analysts puzzled as to the lack of serious exploration of a nuclear weapons capability.

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[56] Barkey, "Turkey's Perspectives. . . ."

[57] One must be careful with this generalization because the majority of nuclear weapons states—the U.S., Great Britain, France, Israel, and India—are democracies.

Latency and Military Strategy

In 2010, Turkey's National Security Council released its most recent "Red Book" of national security threats. Among the most important changes were the removal of Iran, Iraq, Syria, Bulgaria, Georgia, Armenia, Russia, and Greece from the list of threatening countries, and the addition to that list of Israel. Another important change was the inclusion of cyber terror as a major threat.[58] However, despite removing all these enemies, defense procurement is expected to peak in 2015, including the purchase of fighter jets, attack helicopters, and diesel submarines, at more than $4 billion per year. In 2015, a partnership led by Turkey's own Otokar is expected to complete the design, development, and manufacture of four prototypes of the Altay, the country's first domestically produced battle tank. Turkey has also started co-production with Germany of four modern diesel submarines, and is expected to select a U.S. or European partner for the joint manufacture of hundreds of utility helicopters for the military.[59]

Stephen Kinzer suggests that in the aftermath of the Ottoman empire's collapse, Arab leaders remade the Middle East as the Arab world. However, the weakness of the Arab states, and the toppling of the Iraqi regime, have brought that system to an end. The new Middle Eastern powers are the previously marginalized, non-Arab states of Iran and Turkey. Kinzer suggests that Iran and Turkey might replace Israel and Saudi Arabia as key U.S. allies in the region. But this perspective misunderstands that Iran acquiring nuclear weapons is a fundamental security issue for the U.S., not just a matter of regional power.[60]

Faced with a nuclear Iran, Turkey might have options for defense other than pursuit of its own weapons. But multilateral or regional defense options are unlikely to counter the increased influence that Iran will accrue in all actions short of war. Regarding "global zero," or even a Nuclear Weapons Free Zone in the Middle East, Turkey could benefit most from the denuclearization of both Iran and Israel. Its industrial base and conventional military strength would increase in influence under such conditions.[61]

Although Turkey was formally declared a candidate state for EU membership at the Helsinki summit in 1999, and formal accession negotiations started in 2004, the 50th anniversary of the European Economic Community signing the Ankara treaty in 1963 may ironically be celebrated by Turkey's abandonment of the drive toward integration in the EU.[62] By some counts Turkish public support for EU membership has already dropped to 30 percent. Furthermore, Turkey has recently taken steps in the opposite direction by, for example, removing visa requirements for travelers from Syria (until the Syrian conflict escalated) and Russia, which is incompatible with the EU Schengen system but conducive to gaining support for Turkey in other regions.[63]

Some have argued that EU accession has already been abandoned and that the abandonment is being used as justification for reforms that would otherwise be more difficult, such as limiting the influence of the

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[58] A. Yenidunya, "Turkey Analysis: What Does Ankara's New 'Red Book' of Threats Mean?," *EA World View*, October 31, 2010, http://www.enduringamerica.com/home/2010/10/31/turkey-analysis-what-does-ankaras-new-red-book-of-threats-me-1.html.

[59] Ümit Enginsoy, "Turkey's Defense Costs Up Despite Fewer Foes," *Hurriyet Daily News*, September 2, 2010, http://www.hurriyetdailynews.com/n.php?n=no-enemies-but-more-arms-spending-2010-09-02.

[60] James Traub, "Turkish Dilemma," *Foreign Policy*, June 15, 2010.

[61] Barkey, "Turkey's Perspectives. . . ."

[62] Kibaroglu and Caglar, "Implications of a Nuclear Iran for Turkey. . . ."

[63] Ulgen, "A Place in the Sun. . . ."

military. For the AKP, the loss of EU membership has become a manageable destiny.[64] Others argue that structural problems in relations with the EU, including ongoing tensions with Greece, conflict over Cyprus, and the perception of Islamophobia, may have proven insurmountable.[65] Cyprus continues to be the main challenge to Turkish accession to the EU. Opening ports to ships from the Greek part of Cyprus is particularly contentious.[66]

Recent estimates of Iranian progress toward a nuclear weapon have been substantially revised based on the possibility that scientists with weapons programs experience, including from Russia, have provided expertise. If knowledge transfer is so significant, two concerns are pertinent. The first is the increased importance of ICT in transmission of this knowledge, and the second is that those who are aware of who is talking to whom have to be in the same room with those who understand the potential ramification of what is being said. Modeling these information flows in an accurate and meaningful way is an important way of constraining an otherwise massively expanding set of possibilities. Virtually no state has developed nuclear weapons without support from a superpower or technologically advanced country. One condition for Turkey to succeed would be to secure such an endorsement or to establish a procurement network like A. Q. Khan's.[67]

More to Lose Than Gain

A perfect storm could occur that combines some of the following key elements: Turkish doubts of security guarantees provided by a NATO weakened by expansion and internal friction; collapse of the NPT regime thanks to Iran and North Korea; a pronounced shift in Turkish public opinion to Islamism/nationalism; a declining economy dashing expectations after several years of growth; definitive abandonment by the EU; a Russian revival pushing into the Caucasus and the Caspian; a perceived power vacuum in the Middle East; and/or a sense of abandonment of support on the Kurdish issue. Could such a set of occurrences cause Turkey to acquire nuclear weapons? Even before the AKP came to power, Turkey’s transportation minister reportedly declared that a nuclear bomb would enhance Turkey's security and deterrent capability in a threatening environment.[68]

One countervailing measure would be a U.S. commitment to allow Turkey to use predator drones currently stationed in Iraq to help Turkey in its fight against the PKK. The drones would be moved to Incirlik Air Force Base. Compensation could take the form of greater Turkish cooperation on, for example, U.S. Syrian or Iranian policy, and hosting early warning radar systems as part of the European Phased Adaptive Approach for ballistic missile defense.[69]

Another inhibiting factor is that Turkey is a state that has defined its national security and political and economic interests through alliances and cooperation. It runs serious risks if it decides to cross the line to acquire and deploy nuclear weapons. Being tagged a “rogue state” could seriously damage its economy and

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[64] Ibid.

[65] Kibaroglu and Caglar, “Implications of a Nuclear Iran. . . .”

[66] Abramowitz and Barkey, “Turkey's Transformers. . . .”

[67] Kibaroglu and Caglar, “Implications of a Nuclear Iran. . . .”

[68] Fuerth, “Turkey: Nuclear Choices. . . .”

[69] Dorian Jones, “Turkey Eyes U.S. Drones In PKK Fight,” Radio Free Europe, Radio Free Liberty, November 7, 2011, http://www.rferl.org/content/turkey_eyes_us_drones_pkk_fight/24383897.html.

undermine its entire web of relations with the U.S. and the West. Thus far, the rational choice has been to refrain.[70]

In the short term, Turkey seems to have much more to lose than to gain from pushing toward nuclear weapon acquisition. But the outcome of Iran's nuclear status could have a powerful influence on Turkey's calculations. Then, in 2023, by virtue of elements converging into a perfect storm, or by a deep crisis or new developments at the intersection of S&T and perceived security, the perspectives offered here will surely require revision, and the conclusion may look very different than it does now.

Appendix

All Things Cyber

In 2007, the Bilkent University Computational Electromagnetics Research Center solved the largest integral-equation problem in history, breaking a world record. The group used parallel computing platforms that they built with borrowed equipment from Intel Corporation. The ability to solve these kinds of problems is significant for high-level modeling and simulation, and has applications in defense, health, and other industries.[71] Turkey has made the Top 500 list of supercomputing clusters in the past and is on track to establish itself as a leader in the computing field.

In 2008, Turkey conducted the first known cyber attack drills with the participation of eight private institutions. In 2011, Turkey conducted a cyber attack drill that included government infrastructure,[72] including numerous ministries, TUBITAK, National Police Department, and the military's General Staff.[73] TUBITAK's cybersecurity department engages with other public offices and the private sector, and is NATO's contact in Turkey for cybersecurity.[74]

In 2010, Turkey was being considered for membership in NATO's Cooperative Cyber Defense Center of Excellence in Tallinn, Estonia, and is expected to become a member in 2014. Turkey will bring considerable expertise derived from its NATO-affiliated Center of Excellence Defense Against Terrorism. The Turkish military has reportedly had experience combating the cyber threat in the ongoing conflict with the PKK. Cyber attacks have been on the rise in Turkey, as elsewhere. For example, in 2010, police arrested 23 suspected hackers in 13 Turkish provinces accused of hacking the websites of state institutions.[75]

Turkey has signed the Council of Europe's Convention on Cyber Crime, which was adopted by Parliament in 2011. This clears the path for Turkey to receive urgent support and access to a 24/7 network of

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[70] Udum, "Turkey's Nuclear Comeback. . . ."

[71] S. Özcan, "Turkish Scientists Break World Record with 'Borrowed' Computing Resources," Today's Zaman, March 27, 2077, http://www.todayszaman.com/newsDetail_getNewsById.action?load=detay&link=106600.

[72] "Turkey to Conduct Cyber Attack Drills," *Today's Zaman*, January 21, 2011, http://www.todayszaman.com/newsDetail_getNewsById.action?load=detay&newsId=233089&link=233089.

[73] Ibid.

[74] "IT Firms to Attack Systems in Turkey to Rate Cyber Security," *Hurriyet Daily New*s, January 26, 2011, http://www.hurriyetdailynews.com/n.php?n=it-organizations-to-attack-systems-to-rate-cyber-security-2011-01-26.

[75] A. Bozkurt, "Turkey's Bid to Join NATO's Cyber Defense Team to be Reviewed in May," *Today's Zaman*, April 11, 2010, http://www.todayszaman.com/newsDetail_getNewsById.action?load=detay&link=207062.

cybersecurity. Turkey is in the process of crafting national laws aimed at improving its investigative techniques and cooperative relationships for cybersecurity.[76]

However, Turkey has also passed regulations to filter access to the Internet, alarming many of its citizens. Users will have to choose between one of four filtering packages: family, children, domestic, or standard, a regulation that was supposed to be implemented beginning August 2011. This regulation provoked a significant response, plans to appeal the regulation to the European Court of Human Rights, and political debate within the ruling AKP characterizing the filters as a means to control websites that interfere in people's lives. The opposition Republican People's Party fought against barriers to people's access to information.[77] Like many other countries, Turkey is confronting a maze of organizational, technical, political, and legal considerations associated with cybersecurity. Its significant technical and economic resources ensure that Turkey will be a major player in the cyber realm.

Turkey is also actively entering the global high-tech supply chain. Taiwan-based manufacturer Foxconn, which builds Apple products such as the iPad and iPhone, has chosen Turkey as a strategic production base, investing in one of the biggest industrial parks in the country. Foxconn will also focus on nanotechnology, heat transfer, wireless connectivity, materials science, and green manufacturing processes. The new manufacturing facility will initially produce computers for HP. Foxconn is aiming to employee 3,000 people and make additional investments of $10 million for waste treatment facilities, fiber-optic networks, and warehouses.

Nanotechnology

Researchers in Turkey believe that nanotechnology will pave the way for revolutions in materials science, information technology, medicine, and genetics. The countries working on nano will benefit from greater economic power, and Turkey is aiming to be in the top tier in this field. Turkey sees nanotechnology as a field that it can invest in to reverse the brain drain of young scientists who have left to work abroad, mainly in the U.S.

Nanotechnology research in Turkey moved from theoretical, individual-based studies to more substantial collaborative work partly as a result of participation in the EU's FP6. The first National Nanotechnology Research Center was built in the mid-2000s and is an example of Turkey's aspirations for regional leadership in advanced technology. The center works in fields such nanoelectronic, photonic, and lithographic materials. Specific applications include nanotubes, nanowires, quantum dots, magnetic molecules, and frictionless surfaces.[78] Current studies include sensitive missile detectors for planes, atomic powered microscopes, nanotechnology, and energy experiments. A major area of research is hydrogen storage. The biggest problem is that it cannot be stored in sufficiently small areas and requires either high pressure or nanotechnology. In research on fuel cells for automobiles, researchers have increased storage capacity to 22 percent from 6 percent. Another area of focus is frictionless surfaces. Some estimates of economic loss due to friction and corrosion account for 4 percent of national income, or $11 billion in 2004.

Activities such as the 2010 workshop on cleanroom laboratories, which brought researchers from North Africa, Central Asian Turkic republics, the Balkans, and Eastern Europe, enhance Turkey's reputation and

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76 "Turkey to Conduct Cyber Attack Drills. . . ."

77 E. D. Şenerdem, "Turkish Internet Filtering Plan 'Unconstitutional," Experts Say," Hurriyet Daily News, May 4, 2011, http://www.hurriyetdailynews.com/n.php?n=internet-filter-2011-05-04.

78 A. G. Dumanli and Yuda Yürüm, "Nanotechnology in Turkey," Sabanci University, December 12, 2005, http://digital.sabanciuniv.edu/elitfulltext/3011800000123.pdf.

influence.[79] A complex web of universities, research organizations, government organizations, and elements of the private sector must come together to advance beyond high aspirations to produce concrete results.

Lasers/Photonics

The Institute of Electrical and Electronic Engineers' Photonics Society, Turkish Chapter, was established in 1999. Its meetings cover work in Turkey on optical materials and structures, devices, and systems, bringing together scientists, engineers, decision makers in academia, national research institutes, industry, and funding agencies. In addition, several universities house photonics-related research groups.

TUBITAK also has several research laboratories active in photonics with state-of-the-art calibration and testing capabilities, and high precision interferometers. The National Research Institute of Electronics and Cryptology recently started research on quantum key distribution. The Gebze Marmara Research Center Institute of Materials and Advanced Laser Technologies recently developed a laser-based, remote-sensing technology that from 20–40 kilometers away can detect possible chemical or biological attacks, sending wavelengths on the nanoscale.

In the private sector, the display manufacturer Beko, which is now part of Arcelik, and Vestel, supply 20 percent of the TVs sold in Europe. Aselsan, the leading defense and research and product company, has a large division dedicated to electro-optical systems. It also develops advanced photonics products such as laser range finders and cooled and uncooled thermal imaging cameras. Oz Optics has a manufacturing facility for fiber optics components in Izmir, and Hes Fiber in Kayseri carries several fiber-optic cable products.

The World Bank supports several activities, including a high-tech small-business incubator in Adana. In 2007, the incubator housed 32 active enterprises, including one exploring the application of laser technology for health care.[80]

Turkey also recently opened its first accelerator institution at the Ankara University Gölba□ı campus. The new facility is expected to contribute to research in lasers, biotechnology, nanotechnology, health, communications, security, environment, and genetics. Turkey is also expecting to be approved for membership to CERN, the world's largest particle physics laboratory established by 12 European States in 1954.[81]

Advanced Manufacturing[82]

Until the end of the 1980s, most Turkish companies were focused on mass production, assembly, marketing, and sales, with high-value-added work done in the EU or U.S. The economic reforms of the 1990s opened domestic industry to global competition. This in turn caused local manufacturers to start their own R&D programs, with the first 3D printer installed in 1993 by Arcelik, Turkey's largest consumer products and white goods manufacturer. By 2003, with extensive support from government R&D funding, Arcelik became the largest lab in Turkey, and one of the largest in Europe. Arcelik also installed the first

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[79] "Turkey to Teach Nanotechnology to its Neighbors," *Hurriyet Daily News*, February 24, 2010, http://web.hurriyetdailynews.com/n.php?n=turkey-to-teach-nanotechnology-to-its-neighbors-2010-02-24.

[80] "Paving the Way for High Value-Added Businesses in Turkey," World Bank, 2007, http://go.worldbank.org/OVGGSH7FY0.

[81] "Turkey's 'CERN' opens in Ankara," *Hurriyet Daily News*, May 9, 2011, http://www.hurriyetdailynews.com/default.aspx?pageid=438&n=turkey8217s-8216cern8217-opens-in-ankara-2011-05-09.

[82] E. Negis, "A Short History and Applications of 3D Printing Technologies in Turkey," Synergy Publishing and Consulting, September 24, 2009.

direct metal fabricator in Turkey, for rapid tooling applications, although Hofmann Turk has the most direct metal sintering capabilities. Other early adopters of 3D printing technology were Aselsan, a military electronics design and manufacturing company, Doktas, and Demirdokum. In 2000, as prices continued to fall, more companies bought 3D printers and adopted 3D CAD software.

In 2003, 3D printing was used to enable the first medical craniofacial implant design, manufacture, and surgery. The technology has also been employed for architectural modeling design and manufacturing. Several firms became rapid prototyping service centers capable of 3D digitizing, reverse engineering, 3D CAD modeling, industrial design, and engineering services.

Japan: The Most Obvious Latent Case

by Carolyn Chu and Michael Nacht

It is arguably the case that of the world's 82 most developed nations, Japan exhibits the largest gap between what it has, in terms of deployed military forces, and what it could have, based on its inherent technological and economic capabilities. Japan's core strengths are familiar to most: for many years, the world's second largest economy measured by gross domestic product, until recently overtaken by China; a highly educated population of more than 125 million noted for its workforce discipline; some of the world's premier research universities, including the University of Tokyo, Kyoto University, and Osaka University, as well as scores of prestigious independent research institutes; and some of the world's most notable corporations, including Nippon Steel, Toyota, Canon, Sony, Bridgestone, Panasonic, Toshiba, Honda, Mitsubishi Heavy Industries, and Fujitsu, to name a few.

In terms of technological innovation, Japan always features prominently in world rankings. One relatively recent study,[1] for example, noted that:

- Measured by percentage of economic output devoted to research and development (R&D), Japan ranks 4th. Israel is first. The U.S. is sixth. Note that the "BRICs," thought to be the great new emerging economies, all ranked much lower: Brazil ranked 31st, Russia ranked 22nd, India ranked 38th, and China ranked 26th.
- Measured by the number of scientific and engineering researchers per capita, Japan ranks third. Finland is first and the U.S. is seventh.
- Measured by patents per capita, Japan is second, trailing only the U.S.

In the authors' combined Global Technology Index, the rankings are: #1, Finland; #2, Japan; and #3, the U.S.

Because of Japan's technological capabilities, the U.S. and others have been concerned for several decades about the possibility of Japan developing and deploying game-changing military capability, especially nuclear weapons. Not only does Japan have much of the necessary technical capacity, but it also has the materials and many of the manufacturing capabilities required. This chapter concentrates on these nuclear-related issues and Japan's approach to technology planning. It also explores briefly what could alter Japan's current nonnuclear policies.

Japan has been constrained from moving down the nuclear weapons path by its Three Non-Nuclear Principles, a Parliamentary resolution (never adopted into law) passed in 1971. The principles are that Japan shall neither possess nor manufacture nuclear weapons, nor shall it permit their introduction into Japanese territory.[2] Obviously, these principles derived from Japan's experience at Hiroshima and Nagasaki, and the Treaty of Mutual Security and Cooperation between the U.S. and Japan, signed in 1951 and amended in 1960. The principles were adopted as part of the arrangement when the U.S. returned Okinawa to Japanese control in 1971. While Japan has continually upheld these principles, there have been occasional efforts to review them, including a 1995 Japanese Defense Agency study that expressed concerns about the credibility of U.S. nuclear security guarantees after the end of the Cold War.[3]

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[1] Richard Florida, et. al., "The World's Leading Nations for Innovation and Technology," Martin Prosperity Institute, October 3, 2011.

[2] "Three Non-Nuclear Principles," Ministry of Foreign Affairs, Government of Japan.

[3] See Gregory Kulacki, "Japan and America's Nuclear Posture," Union of Concerned Scientists Global Security Program, March 2010.

Japan is facing a range of challenges, not the least of which is sustained leadership instability over the past decade. Since 2006, Japan's prime minister has been successively Junichiro Koizumi (2005–06), Shinzo Abe (2006–07), Yasuo Fukuda (2007–08), Taro Aso (2008–09), Yukio Hatoyama (2009–10), Naoto Kan (2010–11, in office at the time of the Fukushima nuclear accident), and Yoshihiko Noda (2011–12), with Shinzo Abe returning to office in December 2012. Eight prime ministers have held office in a little more than eight years. Five have been members of the Liberal Democratic Party, which has ruled during much of the post-World War II era, and three have been members of the Democratic Party of Japan. This extraordinary turnover largely reflects the continued national economic weakness that has plagued Japan for more than two decades, and some issues of corruption and domestic politics, as well as the inability to lead during and after the nuclear disaster at Fukushima in March 2011. The Japanese public is increasingly disappointed with the government's performance. Moreover, Japan suffers from an aging population, a large and growing national debt, and a projected energy shortage, which together compound these political issues.

Will Japan remain a faithful agent of the United State's nonproliferation regime, or will it respond to these issues by developing a more nationalist national security posture backed by greatly enhanced military capabilities? The public's will for further military development remains weak. But it is unclear how the shrinking U.S. defense budget, U.S. economic weakness and political gridlock, rising Sino-Japanese tensions over maritime differences, and the continued erratic threat from North Korea might impact Japan's defense calculus.

Ministry of Defense

For a number of years, Japan's annual Defense White Paper has consistently endorsed the mutual security pact with the U.S. and the importance of maintaining "extended deterrence," namely the credibility of the U.S. to deter effectively Japan's potential adversaries and to work with Japan to defeat them if deterrence fails. Three priority areas for the Ministry of Defense have been featured recently, including the development and use of space for strengthening command, control, communications, computers, intelligence and reconnaissance;[4] keeping cyberspace stable; and environmental conservation.[5] These priorities are in keeping with Japan's military strategy over the past decade.

Two organizational shifts that reflect the growing priority of defense issues are the elevation of the Defense Agency to ministry level—Ministry of Defense—in 2007 and the current plans of the Abe administration to create a National Security Council along the lines of the U.S. National Security Council. Both changes indicate the growing importance of national security issues in Japanese policy and could further suggest a desire by the Japanese elite to create a greater indigenous capacity to make sophisticated national security policy.

Given Japan's proximity to North Korea (as well as China), Japan places heavy emphasis on early warning systems as well as satellite intelligence assets.[6] By relying on early warning and missile defense capabilities, Japan maintains a defensive posture and eschews the development of offensive capabilities. While the threat from North Korea is significantly more salient, China possesses a variety of missile capabilities with far greater range than North Korea's. And although it is not currently likely, China could use its missile

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[4] Japanese law allows for private capital to fund some public infrastructure, including satellites.

[5] "New Efforts Based on Recent Trends," Ministry of Defense, 2011.

[6] *S&T Strategies of Six Countries*: *Implications for the United States* (Washington, D.C.: National Academies Press, 2010).

capabilities to threaten or attack U.S. forces stationed in Japan, especially in the event of another Taiwan crisis.[7]

In 1998, the Japanese government agreed to engage in R&D cooperation with the U.S. on ballistic missile defense.[8] Japan views missile defense as necessary to protect the Japanese homeland and to counter the proliferation of weapons of mass destruction, especially given the "urgency with which the international community must respond to such threats."[9] Further, Japan sees missile defense as a counterweight to such emerging threats as international terrorism and "various situations which might affect peace and safety."[10]

In response to North Korea's detonation of a nuclear device in 2006, Japan accelerated its deployment of missile defenses. The initial plan was to outfit one Aegis-class ship with ballistic missile defense per year starting in 2007.[11] By 2008, Japan had Patriot PAC-3 systems deployed on five bases throughout Japan and two Aegis-class ships with ballistic missile defense capabilities.[12] Japan should have four Aegis class ships equipped with ballistic missile defense capability.[13] All Japanese acquisitions for missile defense capabilities come from foreign military sales from the U.S.[14]

In 2011, the Japanese government launched the Mid-Term Defense Program, which is intended to update the defense forces of the Self-Defense Force in line with the National Defense Program Guidelines. The guidelines offer three goals for update and expansion: effectively deter and respond to contingencies, further stabilize the security environment of the Asia-Pacific region, and improve the global security environment. The emphasis for updates is on versatile capabilities—those systems that can be used for a range of operations and situations. In particular, the Ministry of Defense continues to focus on early warning and surveillance, maritime patrols, air defense, and ballistic missile defense.[15] Military forces in Japan and surrounding countries are shown in the figure below, as of 2010.

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[7] Michael Swaine et al., "Japan and Ballistic Missile Defense," RAND Corporation, 2001. The U.S. Department of Defense characterizes China's strategy for such a contingency as "antiaccess, area denial," seeking to develop a suite of capabilities from antisatellite weapons to anticarrier weapons that would deny or defeat U.S. naval and air forces that would be expected to surge to the western Pacific to defend Taiwan and to deter Chinese military advances. In the event of a shooting war, U.S. forces based in Japan would be a high-priority Chinese target.

[8] Ibid.

[9] Ibid.

[10] Hideaki Kaneda, et al., "Japan's Missile Defense: Diplomatic and Security Policies in a Changing Strategic Environment," Japan Institute of International Affairs, March 2007, 57.

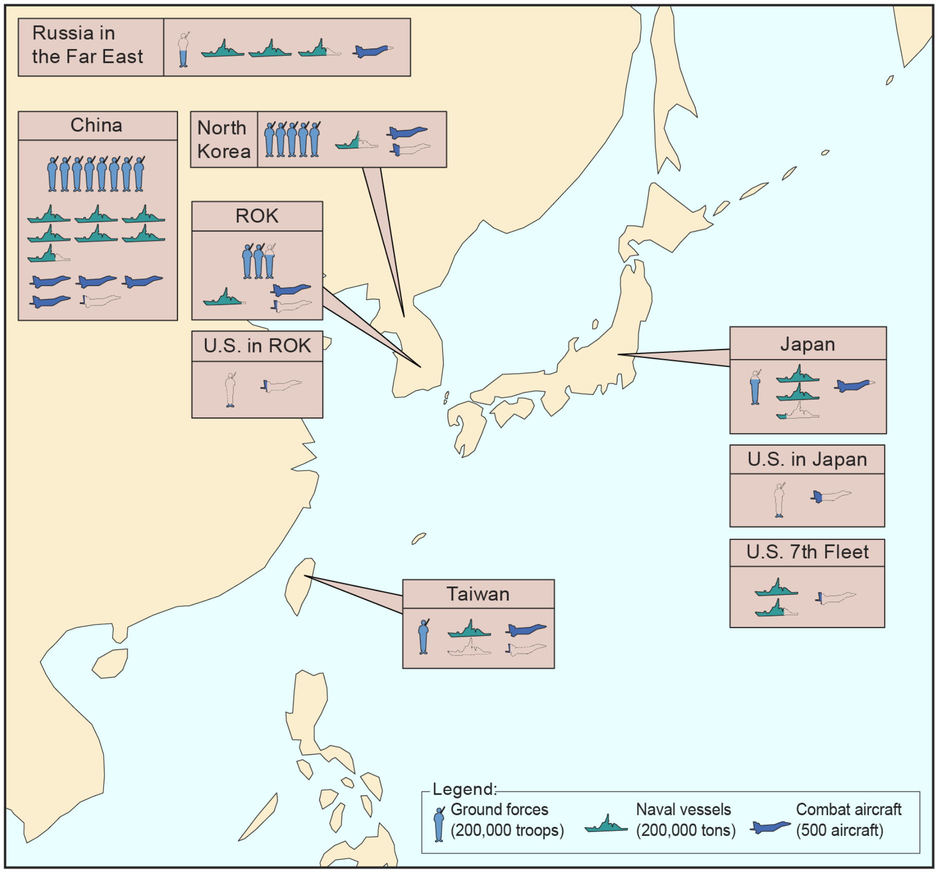
[11] Ibid.

[12] http://www.mod.go.jp/e/jdf/no11/special.html, (as of 2008).

[13] "DDG Kongo Class," http://www.globalsecurity.org/military/world/japan/kongo.htm.

[14] Kaneda et al., "Japan's Missile Defense. . . ."

[15] "Building up the Defense Force in FY2011," Ministry of Defense, 2011.



Source: "The Military Balance 2011," publications of the U.S. Department of Defense and others (actual numbers as of the end of FY2010 are shown for Japan).

Concern over China is driving the deployment of forces to protect Japan's southwest islands, including the acquisition of amphibious vehicles and two helicopter carriers.[16] Moreover, the Self-Defense Force established a Command Control Communication Computer Systems Command in 2008 to develop capabilities for cyber defense of military networks and infrastructure.[17]

Science and Technology

In 2010, Japan spent approximately $144.1 billion on R&D, approximately three percent of gross domestic product (GDP).[18,19] The national strategy for science and technology (S&T) is controlled by the Minister of State for Science and Technology Policy and the Council for Science and Technology Policy. Every five years, the council produces a strategy to guide the next five years of R&D. At the end of 2010, the council released the 4th "Science and Technology Report" for fiscal years 2011–2015. The report lays out five overarching visions for the country:

- Sustainable growth for years to come.
- An affluent, high quality of life for the people.

[16] "The Military Balance 2013," International Institute for Strategic Studies, London, March 14, 2013, 306.

[17] Ibid., 309.

[18] http://online.wsj.com/article/SB10001424052748703734204576019713917682354.html.

[19] https://www.cia.gov/library/publications/the-world-factbook/geos/ja.html.

- S&T as the foundation for national survival (including national security).
- Initiative in solving global issues (including climate change).
- Development of "knowledge" assets and fostering S&T as a culture.

Included within these principles is a goal to increase the industrial competitiveness of Japan, especially in fields that have "high ripple effects in many industries."[20] The strategy focuses on opening up those technology areas in which Japan is already competitive—high-performance electronic devices, information, and telecommunications. Infrastructure investments are to be made in manufacturing technologies to promote advancement in high-precision processing, elemental technologies, and hardware coordination with software. Further, focus is on developing integrated systems for next-generation transportation systems, smart grids, and the like.[21]

According to the report, Japan will promote R&D in ocean exploration (and the development of natural resources), space transportation, satellite development (including information collection), energy resources, nuclear energy (including fast-breeder reactor cycles and nuclear fusion), high-performance computing, geospatial information, and information security. The government of Japan is also to develop a "National Security/Critical Technology Project" to guide and implement particular R&D efforts and investments related to the overarching principles but focused on national security issues. The project will develop action plans, mid- and long-term strategies to execute its mission.[22]

Beginning in 2004, Japan separated its national universities and research institutes from the government's civil service system to allow for greater autonomy and increased cooperation with industry. While Japanese universities used to make up the majority of domestic R&D efforts, industry R&D is increasing. In 2010, Japanese universities conducted 46.5 percent of the country's basic research. In an effort to boost R&D sharing between universities and industry, Japan provides special funds for establishing Collaborative Research Centers for academic–business innovation.[23] (The universities and research institutes that focus on particular technology areas will be addressed below.)

The main source of Japan's defense-related R&D comes from domestic corporations. The special Japan–U.S. relationship provides Japanese companies access to U.S. technologies through licensing and collaboration on various technologies. Because of this partnership, Japanese companies are leaders in the "design and manufacture of materials, components, and electronic subsystems" (crucial to advanced weapons systems).[24] Further, application of commercial technologies to defense requirements has allowed Japan to meet the specifications for advanced defense system (e.g., semiconductors, graphite fiber, opto-electronics, data processing, and telecommunications). While Japan does not currently develop its own ballistic missile defense equipment, it is reported to be able to do so in the future.[25]

Within the Japanese government, the Technical Research and Development Institute (TRDI) serves as Japan's Defense Advanced Research Projects Agency. TRDI develops ground systems, naval systems, air systems, and guided weapons systems, with associated research centers for each of these areas.

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[20] "4th Science and Technology Report (FY2011–FY2015)," Japan Council of Science and Technology Policy, December 2010, 19.

[21] Ibid.

[22] Ibid.

[23] *S&T Strategies of Six Countries: Implications for the United States. . . .*

[24] Ibid., 50

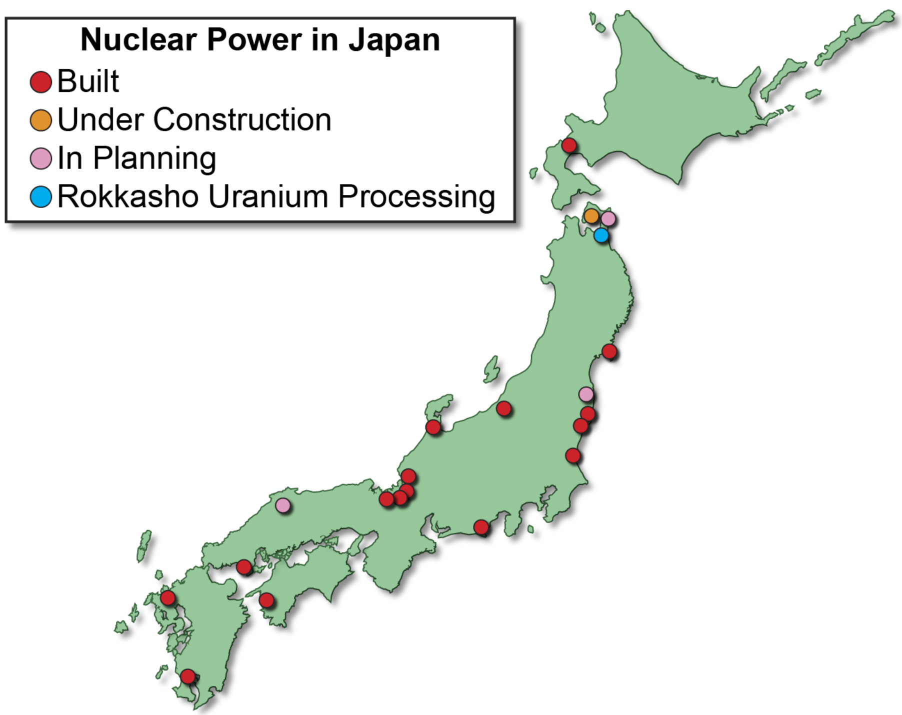
[25] Ibid.

Additionally, TRDI has an Electronic Systems Research Center and an Advanced Defense Technology Center, which work on robot systems, human engineering technology, and future weapons. Recent achievements of TRDI include the development of Type 03 medium-range surface-to-air missiles and an imaging mine detector.[26]

In total, TRDI's 2011 budget was $1.6 million, or 3.8 percent of the defense budget. Seventy-three percent the budget goes to engineering model demonstration and prototyping, while only 18 percent of the budget goes to in-house research and testing.

Nuclear Energy

Japan built its first nuclear power plant in 1966 and has prioritized nuclear energy development since 1973. Prior to nuclear energy development and widespread use, Japan had depended on energy imports for 84 percent of its energy needs. And until the devastating earthquake and tsunami of March 2011 prompted the Fukushima Daiichi meltdown, nuclear energy accounted for 30 percent of Japan's energy needs, with 51 nuclear reactors across the country with a capacity to produce 44,642 megawatts.[27]



Currently, Japan does not have an operational, industrial-level reprocessing plant for spent fuel. It has instead been sent to the United Kingdom and France for reprocessing.[28] A reprocessing facility has been under construction since 1992 but has yet to be completed.[29] Originally, the plant was supposed to be

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[26] http://www.mod.go.jp/trdi/en/about/about_trdi.html.

[27] http://www.world-nuclear.org/info/inf79.html.

[28] "Japan's Nuclear Future: Policy Debate, Prospects, and U.S. Interests," Congressional Research Service, February 2009.

[29] http://cnic.jp/english/topics/cycle/rokkasho/rokkashodata.html.

finished in 1997 but has been delayed 18 times.[30] The plant, located in Rokkasho in the northern part of the country, has been plagued with problems, especially the vitrification plant for high-level fuel that is at the end of the process.[31] There is an experimental reprocessing plant in Tokai on the western coast, but it is currently being used to conduct R&D for fast reactor fuels.[32]

Delays in the development of the Rokkasho reprocessing plant have raised some concerns regarding the proliferation of reprocessing technologies. As such, Japan has tried to make its use of nuclear energy as transparent as possible. By law, all reactor-operating utility companies are required to publically report the amount of plutonium in their possession as well as publish an annual plutonium-use plan. Further, all of Japan's nuclear facilities are subject to International Atomic Energy Agency (IAEA) full-scope safeguards.[33]

Japan has an estimated civilian stockpile of 6.7 metric tons of separated plutonium stored domestically, and 38 metric tons stored outside of the country. This sufficiently separated plutonium could be used to make over 1,000 nuclear weapons. While it would be feasible for Japan to develop nuclear weapons from a technological perspective, the 1995 Japan Defense Agency study, cited previously, found that due to Japan's geography and concentrated population, the political and economic costs of building the infrastructure for a nuclear weapons program would be "exorbitant."[34] Other challenges Japan would face in developing a nuclear weapon include bomb design, reliable delivery vehicles, and intelligence assets to protect and conceal assets.[35] Further, because all of Japan's nuclear facilities and material are under IAEA safeguards, concealing a clandestine weapons program would be difficult.[36] Moreover, these considerations do not address its effect on relations with the U.S., which remain central to Japanese national security strategy.

Nuclear energy research is funded through the Ministry of Education, Culture, Sports, Science and Technology (MEXT), which has the largest R&D budget of any Japanese ministry. The 2011 budget provides MEXT almost $32 billion in research funds (over 70 percent of the national R&D budget).[37] The Japan Atomic Energy Agency, within MEXT, is the main government arm conducting nuclear power research and is the main organization for developing disposal technology.[38]

In 2011, Hitachi, in partnership with General Electric, successfully completed a proof of concept for laser-based uranium enrichment. Currently, this research is being performed in the U.S., and G.E. has petitioned the U.S. government to allow it to construct a plant devoted to laser enrichment, capable of producing

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[30] http://cnic.jp/english/topics/cycle/rokkasho/rokkashodata.html.

[31] http://www.world-nuclear.org/info/inf79.html.

[32] "Japan's Nuclear Future…"

[33] Ibid.

[34] Ibid.

[35] Ibid.

[36] Ibid.

[37] "Japanese Government S&T Budget Proposal FY2011," National Science Foundation, Tokyo Regional Office, February 17, 2011.

[38] "Plan for Meeting the Midterm Goal," Japan Atomic Energy Agency, October 2005.

enriched uranium to fuel 60 large nuclear reactors. Not only does this development significantly lower the cost of enrichment, but it also could make enrichment facilities more difficult to detect.[39]

The 8.9 Richter-scale earthquake of March 11, 2011, changed the picture of nuclear power completely. The 15-meter tsunami off the east coast of Japan caused massive destruction and cut off the power supply and cooling system to the Fukushima Daiichi Nuclear Power Plant, causing three of the four cores to melt within three days. After two weeks, the compromised reactors were stabilized, but no heat sink was established. Cold shutdown took a very long time, although temperatures were below 90 degrees Celsius by mid-October.[40]

Aside from the destruction at Fukushima, more than 14,000 people were killed by the tsunami and over 10,000 people remained missing months after the event.[41] Additionally, thousands were homeless for long periods, either because their homes were destroyed or they were not permitted to return to their homes given the proximity to Fukushima.[42] The psychological impact on those affected has been pervasive, with many diagnosed with post-traumatic stress disorder, as was the case following the Chernobyl meltdown.[43]

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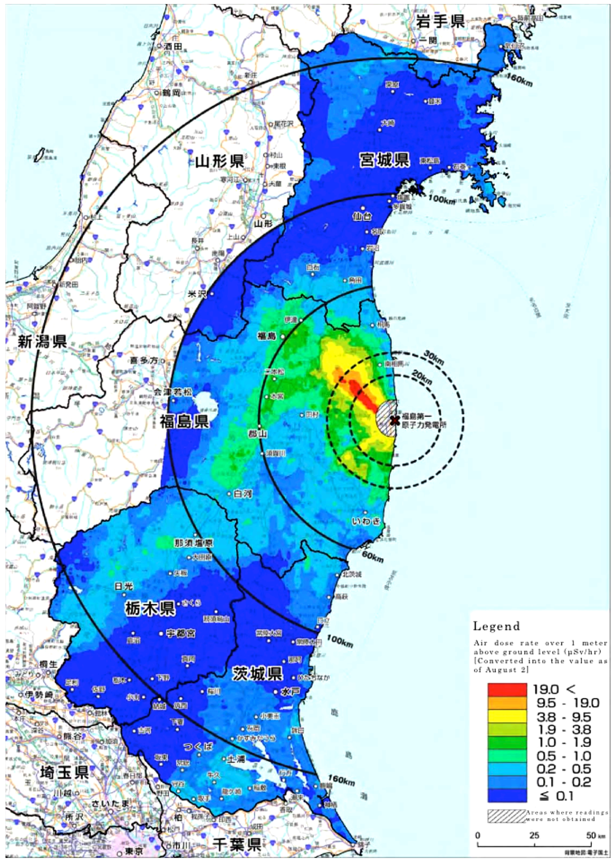
[39] William Broad, "Laser Advances in Nuclear Fuel Stir Terror Fear," *New York Times,* August 20, 2011. http://www.nytimes.com/2011/08/21/science/earth/21laser.html?pagewanted=1&_r=1&emc=eta1.

[40] http://www.world-nuclear.org/info/fukushima_accident_inf129.html.

[41] IAEA Mission report, http://www-pub.iaea.org/MTCD/meetings/PDFplus/2011/cn200/documentation/cn200_Final-Fukushima-Mission_Report.pdf.

[42] http://tohokugeo.jp/disaster/articles/e-contents28.pdf.

[43] http://www.google.com/hostednews/afp/article/ALeqM5gkQeiGPyfYZ1kVGE-zH983l0ibZA?docId=CNG.d99e656d1ef63b2cb2099a758bfbd2e9.2d1.



Exposure to radioactivity based on aircraft monitoring (IAEA)[44]

By May 2011, Japan had slipped into a recession, with GDP decreasing twice as much as predicted.[45] And the economic impact continues to grow. As of early September 2011, only 11 of 51 Japanese nuclear reactors were functioning, potentially causing energy shortages and affecting manufacturing. Two years later, Japan had shut down all of its reactors.[46] The damage from the earthquake (the most severe in the history of Japan), tsunami, and nuclear meltdown is estimated at over $300 billion, which is equivalent to the damage of three Katrina hurricanes.[47] The catastrophe was complicated by charges that the Tokyo Electric Power Company, or TEPCO, and the central government of Japan mishandled the incident and made false claims about the safety of the area afterward. Allegations of radioactive contaminated water persisted more than two years after the incident.

The situation at the Fukushima plant and environs remains serious, and the Japanese government has declared areas around the plant off-limits for two decades.[48,49] Political will for nuclear energy may be

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[44] IAEA Mission report. . .

[45] http://www.guardian.co.uk/world/2011/may/19/japan-earthquake-tsunami-recession.

[46] "Japan Shuts Down Last Nuclear Reactor," CNN, September 16, 2013.

[47] http://www.bloomberg.com/news/2011-03-23/japan-sees-quake-damage-bill-of-up-to-309-billion-almost-four-katrinas.html.

[48] http://www.iaea.org/newscenter/news/tsunamiupdate01.html.

[49] National Public Radio series on Japan disaster, http://www.npr.org/templates/rss/podlayer.php?id=134454848.

deteriorating. Prior to leaving office, Prime Minister Kan stated that Japan should phase out nuclear power over the long-term. His successor, Prime Minister Noda, did not go that far, but he stated that Japan should reduce its reliance on nuclear power.[50] Prime Minister Abe has accelerated the closure of the entire nuclear establishment.[51]

As such, the long-term domestic impact of the Fukushima disaster is unclear. The relationship with the U.S., however, was strengthened, at least in the short term. In the immediate aftermath of the disaster, the U.S. sent humanitarian aid and military assistance (search and rescue), and provided independent expert assessments of the impact of the Fukushima disaster. Often, these assessments provided higher estimations of the level of radioactivity than were provided by Japanese officials. As a result, there was increasing Japanese support for the U.S., which the population saw as being honest with Japanese citizens while the Japanese government was less transparent and forthright.[52] Whether this U.S. support will remain or dissipate is uncertain.

Cybersecurity

While Japan has no equivalent to the U.S. Cyber Command, the Information Security Policy Council creates Japan's overall strategy for information security. In 2006, the council produced the first national strategy nested within the broader national objectives of "(1) continued development of Japan as a major economic power, and use and utilization of IT, (2) realization of better lives for the people and use and utilization of IT, and (3) ensuring us national security from a new perspective."[53] The overall aims of the strategy were to increase domestic awareness regarding risks to information security, create a framework for policy development, and take the initial steps toward developing preventative measures.[54] The second strategy, which was launched in 2009, aims to make preventative measures routine, develop ex-post measures and recovery activities, and incorporate more entities into the protected network, including critical infrastructure, enterprises, and individuals.[55] The National Information Security Center operationalizes the strategy as outlined by the council and works with government agencies and industry to coordinate execution. The Ministry of Defense participates in response drills and provides information regarding attacks on its networks, but it only maintains the security of its own networks.[56]

The Japan Cyber Clean Center, under MEXT, monitors 76 Japanese Internet service providers and covers 90 percent of Japan's Internet users. The center is particularly concerned with bots (automated attacks on

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[50] http://www.bbc.co.uk/news/world-asia-pacific-14895182.

[51] The closure of domestic nuclear operations has not curtailed Japan's commercial activities. Notably, Turkey and Japan signed a formal agreement to build a second nuclear plant in the Black Sea province of Sinop. This is a follow-up to a $22-billion deal in May 2013 for the construction of a 4,800-megawatt plant by an alliance of Mitsubishi Heavy Industries and the French firm Areva. See "Turkey and Japan sign formal agreement to build second nuclear plant in Sinop," Anadolu Agency, Istanbul, November 4, 2013.

[52] Based on a conversation between Michael Nacht and a senior Japanese government official, May, 2011, San Francisco, California.

[53] "The First National Strategy on Information Security," Information Security Policy Council, February 2006.

[54] "Outline of the Second National Strategy on Information Security," National Information Security Center, 2010.

[55] Ibid.

[56] "New Efforts Based on Recent Trends," Ministry of Defense, 2011.

networked computers that produce denial of services) and developing countermeasures against them. Users can obtain instructions and cleanup tools from the center.[57]

Japanese companies, given their technical skill in manufacturing and robotics, are often a target of cyber attacks, which is exacerbated by access to American-designed weapons systems and radar technology. An important attack came to light in September 2011 in which Mitsubishi Heavy Industries, which builds F-15 fighter jets, and other Japanese companies were subjects of cybersecurity breaches. The extent of the breach has not been made public.[58] The Japanese Diet was targeted in a cyber attack as well. Computers in the Diet were infected with a virus that may have allowed the attackers access to sensitive government information. The method of attack appears to have been through a phishing e-mail.[59]

Government-funded cyber research is conducted at the National Institute of Informatics (NII), which is supported through MEXT. Research at NII focuses on network research and software development, both theoretical and applied. NII is formed by a multi-university network, which also maintains and operates the Cyber Science Infrastructure (CSI).[60] CSI is an academic cyber infrastructure used for scientific research. Cross-disciplinary research occurs over CSI, including high-energy physics, supercomputing, nanotechnology, genetics, and astronomy.[61]

Cyber research is extensive in Japanese industry. In June 2011, Fujitsu and RIKEN revealed their joint-venture "K Computer," which was then the fastest supercomputer in the world. The K computer is made up of 68,544 CPUs and performs at 8.162 quadrillion floating-point operations per second (petaflops). The K computer was developed under the High-Performance Computing Initiative initiated and led by MEXT.[62]

Where Is Japan Headed Technologically?

Japan continues to invest in a broad array of technologies at the rate of about 1 percent of GDP. Its priorities in the 3rd S&T basic plan identified four priority areas: life sciences, information and telecommunication, environmental sciences, and nanotechnology, with additional priorities in energy and manufacturing technology, among others. The 4th plan modified the priorities in light of Fukushima, emphasizing reconstruction and revival from the disaster; promoting green innovation including lower carbon energy source usages; promoting life innovations including revolutionary disease prevention; and system reforms aimed at promoting S&T innovation.[63]

Note that the Ministry of Defense allocates less than 5 percent of Japan's research and development, whereas MEXT accounts for more than two-thirds. MEXT supports a network of more than 25 research institutes that provide the majority of research in the nuclear, cyber, laser, and nano fields. Other research institutes associated with the Ministry of Economy, Trade, and Industry focus on bio and other manufacturing technologies; institutes associated with the Ministry of International Affairs and

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[57] https://www.ccc.go.jp/en_ccc/.

[58] http://www.nytimes.com/2011/09/22/world/asia/us-expresses-concern-over-cyberattacks-in-japan.html.

[59] Ibid.

[60] http://nii.ac.jp/en/about/.

[61] "Cyber Science Infrastructure for Boosting e-Science in Japan," National Institute of Informatics, Japan., October 23, 2006.

[62] http://www.fujitsu.com/global/news/pr/archives/month/2011/20110620-02.html.

[63] "4th Science and Technology Report (FY2011–FY2015)," Japan Council of Science and Technology Policy, December 2010.

Communications support research on communication technology; and still other institutes are related to the ministries of the Environment; Agriculture, Forest and Fishery; and Health, Labor and Welfare.

Osaka University's Institute of Laser Engineering is considered Japan's leading laser research facility. It supports three fusion projects, developed a petawatt laser, and is developing an extreme ultraviolet light source for future microprocessor manufacturing.

Among Japan's R&D highlights are:

- Several of the top 100 supercomputers.
- The world's highest solar-power conversion efficiency, producing half of the world's solar power.
- The world's leader in industrial robots for manufacturing.
- Seven of the top 20 semiconductor manufacturers.
- The Cyber Clean Center that covers 90 percent of Japan's Internet users.
- Nanostructure research for advanced materials fabrication.

In terms of the major components required to fabricate nuclear weapons, it is judged that Japan is:

- Very strong with respect to required materials.
- Strong on the necessary technical expertise.
- Strong on the platforms to deliver nuclear weapons.
- Adaptable to the required manufacturing techniques.
- Weak with respect to guidance systems and command and control.

A Nuclear Armed Japan?

The likelihood is that Japan will retain its high-technology, defense-oriented, nonnuclear national security posture. Its nuclear "allergy," stemming from World War II and the Fukushima disaster, and the importance of retaining close ties to the U.S. for security and economic reasons, are very powerful disincentives to move down the nuclear path. However, is worth briefly citing a few scenarios that could completely alter this position:

- The U.S. attacks and invades North Korea without consulting Japan. Japanese territory is then attacked, and Japan undertakes a crash program to deploy a nuclear weapon that would deter a North Korean nuclear attack.
- Because of economic weakness and political gridlock, the U.S continues to reduce its defense budget and its nuclear arsenal. Japan seriously questions the credibility of U.S. security guarantees and turns to nuclear weapons for its own defense.
- China continues to press its claims in the South China Sea. Sino-Japanese tensions rise dramatically, and because of lack of trust in U.S. security guarantees, Japan moves rapidly to acquire nuclear weapons to deter Chinese aggressive action.
- A bold, charismatic nationalist becomes Japan's prime minister and argues persuasively that after more than seventy years since World War II, it is time for Japan to be an independent nuclear weapon state. The prime minister notes that India and Israel have acquired nuclear weapons, maintained their democratic domestic institutions, and remain close, though not treaty-based allies, of the U.S.

To do justice to these scenarios, one would have to engage in detailed scenario-planning exercises to explore in depth the motives and alternatives of each scenario, which is not feasible in this chapter. The likelihood of the occurrence of each scenario would appear to be low.

The point is that Japan has many, although not all, of the ingredients needed to acquire nuclear weapons. It is vitally important that comprehensive and deep interaction be maintained between Washington and Tokyo to ensure that the strength of extended deterrence remains apparent and the need for a Japan nuclear program is viewed by the Japanese public and elites as dangerous and unnecessary.

Lessons from Innovation in Brazil, Russia, and South Korea

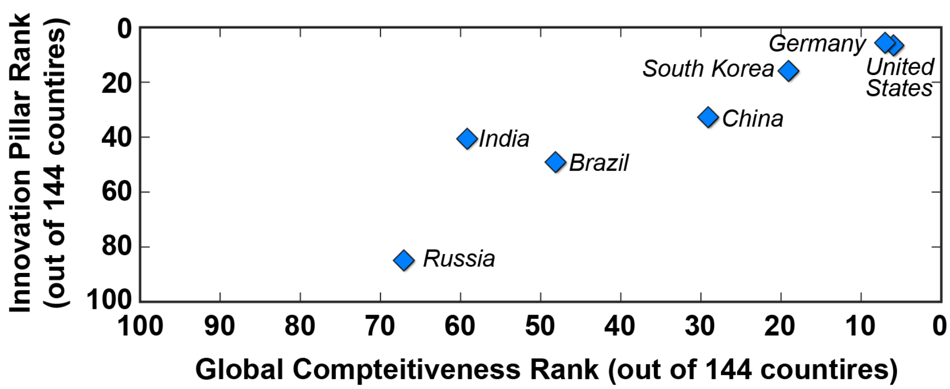
by Stephanie Shipp and Nayanee Gupta

Toward a Definition of National Innovation

A national innovation system emerges from the belief that a country's technological capabilities are its primary source of competitive performance and that these capabilities can be built through national action.[1] A nation's innovation system is shaped by how the nation leverages its endowments—natural resources, culture, history, geography, and demographics—through policies that create a thriving market-oriented economy and accelerate the transition of new technologies, processes, and services to the market.[2] The core of a nation's innovation system, then, are its endowments and how government and industry leverage these endowments—the nation's government through policy investments, incentives, and regulations and industrial firms through strategies, investments, and training.

Given this perspective, this chapter examines the innovation policies of three countries—Brazil, Russia, and South Korea—that have been unique in their ability to leverage their national endowments to shape innovative capacity in the global market. These countries were chosen because they are emerging, state capitalistic countries, each at different levels of competitiveness and innovation capacity. The chart below plots the World Economic Forum's overall Global Competitiveness Index, and one of its twelve components, innovation, for each of the countries of interest.

This chart shows where Brazil, Russia, and South Korea rank across 144 countries with respect to their global competitiveness and innovation. As the figure shows, South Korea ranks very high, approaching the same level of global competitiveness and innovation capacity as the U.S. and Germany. Brazil is in the top third, and Russia is in the middle, based on the rankings for global competitiveness and innovation capacity of the 144 countries.[3]



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[1] Richard R. Nelson, ed., *National Innovation Systems: A Comparative Analysis* (New York: Oxford University Press., 1993).

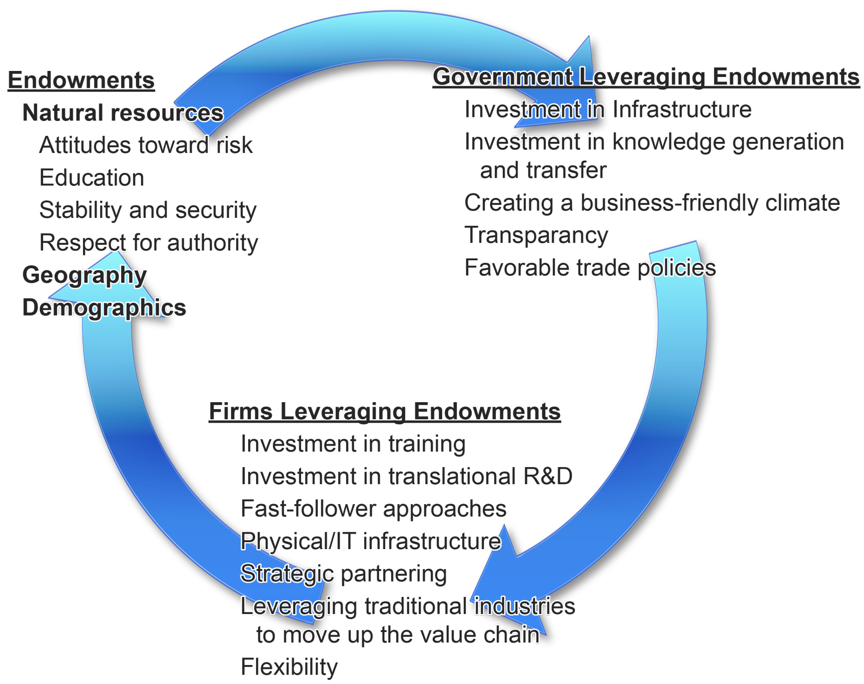
[2] Lewis M. Branscomb and Philip E. Auerswald, "Between Invention and Innovation: An Analysis of the Funding for Early Stage Technology Development," National Institute of Standards and Technology, NIST GCR-02-841, November 2002, http://www.atp.nist.gov/eao/eao_pubs.htm.

[3] Since 2005, the World Economic Forum has conducted a competitiveness analysis to create a Global Competitiveness Index (GCI), a comprehensive tool that measures the microeconomic and macroeconomic foundations of national competitiveness 144 countries and collects. They define competitiveness as "the set of institutions, policies, and factors that determine the level of productivity of a country. The level of productivity, in turn, sets the level of prosperity that can be earned by an economy. The productivity level also determines the rates of return obtained by investments in an economy, which in turn are the fundamental drivers of its growth rates." World Economic Forum (Global Competitiveness Index), http://reports.weforum.org/global-competitiveness-report-2012-2013/.

For this study, we define innovation as the introduction of a new, or improved upon, product, process, model, or service in any field that produces a new advantage or value, and is either widely disseminated into the market or influences the market such that economies are impacted.[4] Stone et al.[5] describe the breadth of the term by pointing to its presence in new or improved products, processes, experiences, or business models, and this definition covers a broad spectrum of business activity. Innovation is often spoken of as an interconnected innovation system because it is not limited to only science and technology (S&T) but can cross over into many fields, such as business practices, design, and services. By definition, it requires successful transition into the economy.

The concept of a *national* innovation system was proposed in the 1990s by economists Freeman, Lundvall, and Nelson.[6] These and other economists attempted to explain the relationship between a nation's investment in S&T and its economic development. In contrast to an innovation system in general, a national innovation system is made up of primary actors whose relationships and interactions foster innovation within a nation.

The following figure shows the interconnections among the three primary components of a national innovation system—endowments, government leverage, and industry leverage—and indicates their influence on each other.[7]



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[4] "Oslo Manual: The Measurement of Scientific and Technological Activities: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data," Organisation for Economic Co-Operation and Development, 2005.

[5] A. Stone, S. Rose, B. Lal, and S. Shipp. "Measuring Innovation and Intangibles: A Business Perspective," Institute for Defense Analyses/Science and Technology Policy Institute, 2008.

[6] Chris Freeman, "The National System of Innovation in Historical Perspective," *Cambridge Journal of Economics* **19**, 5–24, 1995; Bengt-Ake Lundvall, ed., *National Innovation Systems: Towards a Theory of Innovation and Interactive Learning* (London: Pinter, 1992); and Richard R. Nelson, ed., *National Innovation Systems: A Comparative Analysis* (New York: Oxford University Press, 1993).

[7] B. Lal and S. Shipp, "National Innovation Systems: Invention to Innovation," in *Unlocking the Potential of the U.S.-Japan-Europe Relationship* (Washington, D.C.: German Marshall Fund of the United States, 2013), http://www.gmfus.org/wp-content/blogs.dir/1/files_mf/1381865232TokyoTrilateralCollection_Oct13_web.pdf.

A national innovation system is interdependent and synergistic. Government policies can enhance national endowments by creating policies that develop an educated workforce, encourage entrepreneurship, and strategically enhance natural resources. These policies can create the right conditions for firms to invest in and build companies that continue to educate their workers and build physical and information technology (IT) infrastructure. Each stage of the process feeds into the next, so that a healthy innovation system continues to develop. The process, when successful, advances the competitiveness of a country, leading to improved productivity, standard of living, and innovativeness, the underpinnings for economic and national security. These strategies are not necessarily linear.

National governments have a range of motives for pursuing innovation. Chief among them is economic development to increase national wealth and prosperity via the creation of new products and services and, in turn, high-paying jobs. For high-wage countries such as South Korea, this approach may mean having more attractive products or better production processes than firms in low-wage countries. For emerging countries such as Brazil, it may mean creating a bottom-up entrepreneurial system to balance a successful top-down approach to creating world-class companies. Russia, with its well-educated populace, especially in science and engineering, is creating special economic zones to encourage bottom-up entrepreneurship. These countries face many challenges, and how they adapt to them through policies and market practices will shape their current and expected innovation capacity.

Endowments such as a nation's size and natural resources provide comparative advantages and drive conscious decisions to develop and sustain economic strength in certain areas. Countries with abundant natural resources, for example, may benefit from revenues and foreign investment that leverage those resources. Countries such as Brazil and Russia have abundant natural resources, while South Korea does not. However, natural resources are not a nation's only endowments. Socio-economic, cultural, and political circumstances are also important. South Korea has compensated for its lack of natural resources by achieving the highest literacy rate among Organization for Economic Cooperation and Development countries. The government has accomplished this achievement by investing heavily in education, S&T, and "knowledge-based" industries (called *chaebols*). Brazil designed many of its policies to take advantage of natural resources in agriculture and energy, while balancing the development in sectors that capitalize on engineering skills. Russia has relied on its natural oil and gas resources at the expense of developing other sectors, resulting in what is sometimes called a "resource curse."[8]

Differences in endowments change how a government structures its innovation policies. Hence, government policies of the nations explored here use various fiscal, monetary, and trade policies to further their innovation goals. When policies combine to make exporting attractive, some nations have built export-oriented innovation systems. Policies that protect industry provide subsidies, preferential government procurements, and support research and development (R&D), all to nurture emerging industries.

In addition to contributing to a nation's comparative advantage, a nation's size and natural resources also drive decisions to develop and sustain certain economic strengths. Brazil's natural resource endowments attract billions in investment from China alone. They also allow Brazil to focus on agriculture and bio-diversity research through the government research corporation Embrapa. Brazil, not having a strong post-secondary education system, developed a Science without Borders plan, sending 100,000 students to

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[8] This resource curse explains the relationship between the increase in exploitation of natural resources and a decline in the manufacturing sector. The increase in revenues from natural resources makes the nation's currency stronger, resulting in exports being more expensive for other countries to buy, thus rendering the manufacturing sector less competitive. This important feature helps explain Russian economic behavior and those nations with similar characteristics.

the best universities overseas. As is evident in the example of Russia, availability of an educated workforce is not enough by itself. The economic incentives must be sufficient to induce them to mind the market and to take advantage of the presence of a skilled workforce.

Governments can promote policies that make the business environment more favorable to foreign investors, including specific ways to address industrial mergers and acquisitions, inter-firm agreements and joint ventures, and creating analogs to venture capital. In Russia, for example, the government has set up two new innovation centers—Skolkovo[9] and Innopolis[10]—to shield foreign investors from corruption and demands of local governments. Both Brazil and Russia have created technology parks to take advantage of expertise in specific regions and to support university collaborations.

While industrial firms draw extensively on external sources such as universities and government laboratories, most of the innovative effort is made within the private companies themselves. Profiting from innovation requires the coordination of R&D, design, production, and marketing, which tend to proceed more effectively within an organization.

Examined through the lens of their national innovation systems, Brazil, Russia, and South Korea have leveraged their endowments with mixed success. The common themes are the development of large, often world-class companies and the presence of manufacturing capacity (a major source of innovation in developed countries). All three have achieved their current innovation state through top-down, state-led policies and incentives to encourage collaborations and startups. Their common goals are to strengthen emerging links between universities and firms that support the development of small- and medium-sized technology-oriented companies. The challenges for the small companies are lack of access to capital and inability to work effectively with cumbersome bureaucratic government systems.

Brazil's National Innovation System

"Brazil's democracy is loud, messy, and imperfect, but overall it has served the Brazilian people well."[11] The same can be said of Brazil's innovation system. Brazil's innovation story is one of contrasts and tensions. Brazil wants to stimulate development, protect the environment, and reach for excellence beyond its historic sectors while increasing the middle class. The nation also wants to develop S&T that competes globally while investing in basic science more broadly and equitably across Brazil.

Brazil's history, natural resources, size, diversity, and growing educated middle class have shaped its innovation evolution. Brazil is committed to using its endowments to cultivate innovation and hence achieve a higher standard of living. Brazil's innovation system is referred to as a "natural knowledge economy" because it is closely tied to its natural resources, endowments, and geography. Brazil has designed policies to develop strong industrial sectors and continues to do so. Examples include recent development of its biofuels industry and research into pre-salt oil reserves.

Brazil's programs are attempting to respond to structural barriers to innovation that include macroeconomic conditions, especially high interest rates. Brazilian companies have the perception that the

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[9] Federal Law No. 244-FZ (2010), "Law on the Skolkovo Innovation Center," sets out the legal framework for the establishment and operation of the Skolkovo Innovation Center and aims to encourage research and development in certain areas. Companies and individual entrepreneurs are granted tax, customs, and other benefits. R. Thornock and W. Whitaker, "Skolkovo: Russia's Emerging Silicon Valley," Knowledge@Wharton., January 26, 2011, http://knowledge.wharton.upenn.edu/article.cfm?articleid=2699.

[10] W. Ford, "In Kazan, Medvedev Begins Construction of Innopolis, Orders New Airplane Factory To Be Built," *Kazan Herald*, June 10, 2012.

[11] L. Rohter, *Brazil on the Rise* (Basingstoke, U.K.: Palgrave MacMillan, 2012.)

government will continue to protect them from competition through import substitution and protectionist policies, which reduce incentives to innovate. It is not clear, however, how long these protections can be sustained if Brazil genuinely seeks to become a world-class power that relies heavily on innovation.

Brazil has focused on innovation since the early 1900s when agriculture and medical research services were first established. Interest in innovation surged in the 1950s with the establishment of national S&T agencies and financing programs, and innovative programs have evolved considerably since 1984 when Brazilian military rule ended. Many policies, including the *Bolsa Familia* social policies, have influenced innovation by reducing poverty and increasing the middle class through programs that spilled over to the banking and financial sectors. Recent programs have built on earlier ones and attempted to address long-term challenges of implementation and coordination across ministries.

Historically, one of Brazil's strengths has been the development of world-class technological capability and strategic establishment of sectors that have been shaped by its geography and natural resources, such as agriculture and deep-sea oil and gas production. Petrobras (the semipublic energy corporation) and Embrapa (the state-owned company affiliated with the Brazilian Ministry of Agriculture) are notable examples, while Embraer (the partially government-controlled Brazilian aerospace conglomerate) is a leading manufacturer of small aircraft. The nation's manufacturing expertise is growing more broadly as an influx of multinational corporations has championed management strategies to empower workers, making the domestic industry more competitive.

While Brazil has been committed since the 1990s to fostering innovation through education and industry policies, the pace of government action and drive for change has accelerated over the past 10 years. Through such policies, Brazil has provided incentives to support collaboration between universities and private firms and to enhance its overall educational system. New sources of capital are emerging, and a network of venture capitalists and angel investors is growing, especially since 2005.

Brazil's state-driven innovation policies, such as *Brasil Major* (Greater Brazil Plan), announced in 2012, emphasize support for local industry by mandating protectionist measures such as high local content requirements, subsidies, and tariffs, which create a disadvantage when coping with competition from other countries (particularly China and India) in emerging markets. *Brasil Major* is focusing on developing specific sectors and encouraging university–private collaborations, with the goal to create startup companies. However, Brazil's economic and innovation policies are perceived by industry as being a patchwork of measures targeting short-term solutions, whose impact thus far has been low.

The *Greater IT Plan* is further developing Brazil's strengths in information technology to promote R&D, entrepreneurship, innovation, and competitiveness in the information technology sector. The goal is to systematically build and enhance the information, communications, and technology infrastructure to meet the accelerating demand for social media, which spurs growth and innovation in e-commerce.

Despite these strengths, the nation also face challenges. The innovation system is bureaucratic, taxes are high, and new infrastructure (such as national transportation systems) is needed. The "*custo* Brazil" (cost of doing business, or "Brazil penalty," defined as the additional expense of goods due to insufficient infrastructure, high taxes and interest rates, and an excessive bureaucracy) makes doing business difficult. It currently takes 119 days to start a new business, which is the fifth longest wait in the world. Brazil is making strides in reducing corruption through legislation and implementation of practices to improve transparency, but it still has a long way to go. As with Brazilian innovation policies, the effects of these changes take time, but they have been noticed by other countries seeking to imitate them.

Innovation depends on the ability to move S&T to the market. Brazil's approach to developing private companies through incentives, loans, subsidies, and technology parks and incubators and by setting them up to have independent management, has succeeded in creating some strong industry sectors. Two examples are supporting the manufacture of aircraft (Embraer) and deep-sea drilling technology

(Petrobras). Brazil did this through government procurement and financial support when private capital was not available, both during the initial start-up phases and when the economy was not strong. Once a firm proves successful, the government takes a minority position in the organization.

State support has enabled Brazil to develop technological capability by growing internal scientific capacity as well as leveraging international collaborations in sectors such as oil and natural gas, biofuels, and avionics and space. Embraer was created to provide transportation for monitoring and accessing Brazil's vast stretches of relatively isolated territory. Today, Embraer is the third largest aircraft manufacturer in the world. While the firm does not compete with Boeing (Embraer's largest airplanes are barely as big as Boeing's smallest ones), it has since 2012 begun collaborating with Boeing on research in aviation biofuels and composites for aircraft design.

Among the challenges Brazil faces in developing and sustaining new industry sectors are low levels of private R&D and noncompetitive technology levels resulting from low involvement in global supply chains. Multinational corporations often do not connect to the vast majority of small- and medium-size companies that serve only domestic or regional markets. Private R&D varies regionally, with Sao Paulo representing almost three-fourths of total R&D expenditures at the state level.

Both economic development and S&T capability are incremental, tailored to the needs of Brazil and the immediate region rather than the world. Through this incremental improvement, Brazil has attained a leadership position in select fields, maintenance of which relies on consistent investment and support from the state. One of Brazil's challenges will be to transition more businesses from the informal (underground) economy to the formal (taxpaying) economy, especially in the creation of startups, encouraging more "tinkering," and reducing the Brazilian *custo*. Brazil is also beginning to be noticed for the innovativeness of its firms—both traditional and newer ones—and foreign companies and countries are seeking to increase their investments in Brazil.

Brazil is known for its cumulative incremental—not disruptive—innovation. There may be glimmers that this is changing. Two of Brazil's top 10 companies made it on the "top 50 most innovative companies worldwide" (noted below), and one of Brazil's top 10 startups has won several awards in Silicon Valley. [12]

- Bug Agentes Biológicos (ranked 33rd in the world)—The company breeds a natural alternative to harmful agricultural pesticides. Bug's mass-produced wasps kill off larvae and stinkbugs before they can threaten Brazil's sugarcane and soybean plants, two of the country's largest cash crops.
- Boo-box (ranked 45th in the world)—The company has built a burgeoning Internet advertising giant in Latin America. The ad network has partnered with the Argentinean social analytics firm Popego to combine forces and offer targeted, social-media-powered advertising across the continent.

Russia's National Innovation System

Russia exemplifies the challenges of aspiring economic security through innovation. Successes in business and innovation are usually achieved by both adapting to and functioning within the prevailing conditions or by circumventing the reach of authority. A vast pool of scientists and engineers, in conjunction with a rapidly growing and demanding middle class, is expected to bring increasing foreign investment in high-technology products in the future.

Russia has natural resources that are widely distributed throughout the country, an educated population with an education system focused on S&T, and funds available for innovation projects. Russia has a presence in space and energy technology, and an increasing number of multinational firms are establishing

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[12] R. Geromei, "Brazil's Top 10 Most Innovative Companies," *Forbes*, February 21, 2012, http://www.forbes.com/sites/ricardogeromel/2012/02/21/brazils-top-10-most-innovative-companies/3/.

R&D and other facilities within its borders. Russia has created more than 200 technology parks and business incubators and 100 centers of technology transfer. However, many experts are skeptical about the positive impact these parks will have, and their economic influence will take time, even if they are eventually successful,

One of the world's biggest suppliers of oil, Russia is highly dependent on its natural resources. This "resource curse" is believed to have inhibited the creation of knowledge-based sectors, unlike countries such as Australia, Norway, and Canada, which have done so despite a heavy dependence on natural-resource income. The state-run oil companies are inefficient and lack innovation in their operations. Russian companies may become less competitive in the long run, given the development of new energy technologies (such as fracking and shale-oil) as well as competition from China, which gives the European Union and other customers of Russia's oil companies more options from which to choose.

Strategy 2020 is one of Russia's first attempts to address innovation policy in a comprehensive approach that mirrors the Western model. It encompasses many sectors of the economy from state-owned corporations to private business and individual programs. The strategy is considered overly ambitious. Many experts posit that specific goals and expectations are well beyond what can reasonably be achieved.

Past innovation policies were applied in isolated environments; only recently have policies emphasized the need for linkages and collaboration. It is too early to speculate on the impact of recent innovation policies, although expectations are meager. One adaptive strategy the government is using is special economic zones, which are enclosed campuses where companies get legal and physical protection to isolate them from corruption and rent-seeking. Two examples are Rusnano, a joint-stock company created and owned by the government and aimed at commercializing developments in nanotechnology, and Skolkovo, an ecosystem with an Institute of Science and Technology, corporate R&D centers, business incubators and accelerators, private seed and venture funds, and start-up companies, as well as residential space and social infrastructure. Recent alleged corruption problems at Skolkovo are creating concern with global partners,[13] and many believe that the Skolkovo's isolation will not benefit the Russian economy.[14]

Russia has strengths in state-supported sectors such as nuclear arms technology, aerospace technology, shipbuilding, electronics, and geology. The legacy systems of the Soviet era—a period of strength in S&T education, defense, and aerospace development—have diminished as a result of large-scale emigration of Russian scientists and engineers over the past two decades. However, Russia still retains much of the human capital developed during the Soviet era, especially in traditional fields such as mathematics and theoretical physics, and government spending on education continues to grow despite economic problems. Russian scientists and engineers are sought by multinational companies expanding their R&D capabilities overseas, particularly in sectors such as aerospace, automotive, and mineral products manufacturing.

For innovation policies to succeed, Russia needs to develop and implement consistent policies that will improve transparency, broaden its economy beyond its reliance on their natural resources, and encourage investment in R&D. Russia lags behind comparable economies in developing the policies and conditions for entrepreneurship, risk-taking, and competitiveness. Many experts suggest that the extent of corruption comes close to outweighing other factors in its effect on the business climate. A legacy of the Soviet Union and a state-controlled economy is the absence of conditions required for innovation (for example, mechanisms for transitioning technology from research to the marketplace) in the domestic economy. A fear of failure still prevails, discouraging widespread entrepreneurship.

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[13] C. Weaver and C. Clover, "Political Backlash Blamed for Woes at Russia's 'Silicon Valley'," *Financial Times*, May 20, 2013, http://www.ft.com/cms/s/0/a9d3bd90-c157-11e2-b93b-00144feab7de.html - axzz2Wt0PrEFr.

[14] H. Balzer, "Learning to Innovate? Education and Knowledge-Based Economies in Russia and China," Mortara Center for International Studies, Georgetown University, 2011.

Russia's domestic industry is primarily composed of large state-owned enterprises in the extraction sector, which are known for their inefficiency. Outside these conglomerates, most firms, particularly small- and medium-sized companies, are far below the European Union average for their number of innovative products. Only one in ten firms invests in R&D and innovation. Other indicators of innovation activity for Russia, particularly those associated with transition of technology, are also weak both domestically and internationally.

On the other hand, an increasing flow of foreign direct investment into the manufacturing and information technology sectors provides some optimism. Collaborations with Boeing, General Electric, IBM, General Motors, and others are being driven by rising demand as well as access to a skilled workforce, and these investments have created new market-driven mechanisms. Multinational corporations are increasingly setting up manufacturing operations jointly with Russian companies, so it is likely that Russia's production in the aerospace, automotive, and materials sectors will increase. Russia's recent entry into the World Trade Organization opens up new opportunities for trading and collaboration, and multinational companies have been encouraged to invest in Russia.

Adaptive strategies in Russia's private sector have developed despite widespread corruption. For example, international automotive companies invest in manufacturing facilities of Russian car companies that are going out of business as a way to avoid stiff tariffs and quickly gain a foothold in one of the fastest growing global automotive markets. Another example is the rapid growth of the IT sector, which has been a positive force for the Russian economy, spurring entrepreneurship and global recognition in areas such as software for security, social networking, and mobile applications. IT provides a space for entrepreneurship and innovation to occur outside the control of the government, and may continue to be a force in innovation. A new wave of entrepreneurship is growing, underpinned by accelerating successes in the IT sector. Many who have benefitted from employment in successful companies are becoming entrepreneurs and investors themselves.

The Russian government is the source of most venture funds; however, the impact of this funding is difficult to gauge. Steadily growing private venture capital from both inside and outside Russia is being invested in Russian companies that incorporate in the U.S. (particularly Delaware) to avoid bureaucracy, including Kaspersky, Yandex, Qiwi, Dressformer, Cardiowave, mail.ru, and Kernel. While this development has not had a large effect so far, it gives investors a chance to seek out talent in small- and medium-sized Russian companies. Some startups have created products and services so that consumers can maneuver in the Russian market.[15] They include:

- QIWI, a reverse ATM where a consumer adds cash to a pre-paid card.[16]
- Dressformer, which helps consumers order the correct size of clothing online to minimize returns.[17]
- Ozon.ru (Russian Amazon), which accepts cash on delivery, because the financial system does not function very well. This requires a sophisticated product delivery system, but could prove to be an innovative model for other developing countries such as those in Africa.[18]

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[15] "10 Most Innovative Companies in Russia," April 22, 2011, http://www.fastcompany.com/1738950/10-most-innovative-companies-in russia. The three companies were initially identified in interviews with experts on business in Russia.

[16] I. Khrennikov, "Cash-Loving Russians Give Qiwi an Edge as PayPal Looms," http://www.bloomberg.com/news/2013-10-01/cash-loving-russians-give-qiwi-an-edge-as-paypal-looms.html.

[17] Gillis Bernard, "4 Standout Startups from Boston's Russian Innovation Week Event," http://bostinno.streetwise.co/2013/09/18/4-standout-startups-from-the-russian-innovation-conference/.

In summary, while glimmers of innovation are emerging, Russia's ability to implement its ambitious strategy to become innovative is hampered by the country's top-down central planning approach and the kinds of relationships that the Soviet legacy has imposed on knowledge creation, transfer, and commercialization.

South Korea's National Innovation System

South Korean companies have moved from safe technology investments and incremental innovation toward cutting-edge science-based innovation. Capitalizing on future possibilities in S&T requires disruption and risk taking. Koreans prize efficiency; their impatience for success leads them to be highly strategic in their approach. They emphasize planning for R&D in government and industry and using metrics to track success. The government's long-term (technology agnostic) investments in basic science R&D, high standards for universities, and emphasis on global collaborations will secure Korea's evolution of a knowledge-based economy but only if paired with an increasing tolerance for risk-taking.

Lacking natural resources, South Korea has focused its innovation policies on developing an intensive educational system that begins in primary education and continues through the university level. The government also ensures that, through its support of industry-oriented research centers, there is a central locus of research and development in the disciplines associated with particular technologies.

The Korean government has developed a robust S&T capacity following two parallel tracks:

- Creation of a state-led research and educational capacity.
- Corporate R&D efforts by the country's large conglomerates.

The government's S&T policy is implemented in the form of S&T basic plans every five years. The most recent, the "577 Initiative," focuses on sector-specific strategies, including automobiles, shipbuilding, semiconductors, steel, machinery, textiles, and materials. South Korea is also developing in three broad areas: green technologies, value-added services, and technology convergence (such as the convergence of telecommunications and network technologies into a single system or device).[19] South Korea has focused historically on manufacturing but as the nation has developed it has shifted the focus to services and creation of a knowledge economy.

To achieve the goal of increasing R&D investments as a share of gross domestic product (GDP), the government launched a variety of financial incentives to encourage private investment in R&D, notably by encouraging private financial institutions to turn their collateral-based loans into technological value-based loans. Many government departments have set up funds for direct financial support to small- and medium-sized companies. Both large and small corporations benefit from tax deductions for research activities and human development cost.[20]

The government also spends extensively on infrastructure; Korea is ranked 13th in the world in infrastructure and leads in broadband penetration.[21] The government's investments have been largely

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[18] I. Khrennikov, "'Amazon of Russia' Ozon.ru Boosts Sales 55%, Eyes Acquisitions," http://www.bloomberg.com/news/2013-03-28/-amazon-of-russia-ozon-ru-boosts-sales-55-eyes-acquisitions.html.

[19] "Industry Policies," Ministry of Knowledge Economy (South Korea), 2011.

[20] Terence O'Donnell, "South Korea SME Innovation Support Schemes: Final Report on IPF Review visit to South Korea," European Commission, IPF 12-013., 2012, http://www.yumpu.com/en/document/view/8934952/south-korea-sme-innovation-support-schemes-pro-inno-europe.

[21] K. Schwab, ed., "Global Competitiveness Report 2012–2013," World Economic Forum, 2012, http://www3.weforum.org/docs/WEF_GlobalCompetitivenessReport.

effective in spurring S&T-based innovation and progress. South Korean companies have achieved high levels of global competitiveness in leading-edge technologies, ranking second globally (behind the U.S.) in innovation in 2013.[22]

Innovation in the South Korean economy is primarily driven by the private sector, which is dominated by the top conglomerates (*chaebols*) such as Samsung, Hyundai, Pohang Iron and Steel Company, and LG Electronics. These firms typically span a broad spectrum of related and unrelated businesses. For example, Samsung is diversified across the food, infrastructure, shipbuilding, life insurance, surveillance, recreation, advertising, and financial industries, among others, leading many to refer to South Korea as the "Republic of Samsung." These four firms control about 70 percent of South Korea's total spending on R&D (with the government contributing about 25 percent). These same four firms were picked by the government in the 1960s to lead Korea's industrial revolution,[23] and they started out deeply rooted in the Japanese model of low-cost manufacturing with a focus on quality and process improvement.

Over the past two decades, South Korea has transformed itself into a leading innovator by adopting Western business practices and making aggressive R&D investments while capitalizing on the strengths of a consolidated manufacturing supply chain. In 2012, Samsung was ranked fourth among the world's most innovative companies, right behind Apple, Google, and 3M.[24] In a different ranking of innovative companies, by 2013 Hyundai had gained the top spot among the automotive companies, moving up 12 rankings to surpass Toyota.[25]

South Korean companies have developed a rapid "do–learn–improve" cycle that allows them to enter the market at the low end of the technology and inundate the market with lower cost products to secure market share. Several years ago, Sony was the first company to make what is widely seen as the next-generation television. It featured the organic light emitting diode (OLED) display that is thinner, more vivid and more energy-efficient than previous displays. However, Sony was never able to mass-produce or market the OLED display because it was too expensive. Samsung and its domestic rival, LG Electronics, entered the market, building mass-production capabilities by first making smaller OLEDs for high-end smartphones and then securing the market on 55-inch OLED televisions.

South Korea has leveraged its manufacturing capacity to grow an innovation-based economy that is the second largest worldwide when measuring manufacturing value added as a percentage of GDP. It is the largest innovation-based economy when measuring investment in manufacturing fixed capital as a share of GDP. South Korean firms maintain close control over their vertically integrated manufacturing supply chains, which allows them to be flexible and change direction more rapidly than competitors who use globally dispersed supply chains. For example, it is estimated that Samsung's control over the manufacturing supply chain gives them a six-month lead over competitors in launching new products.

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[22] "50 Most Innovative Countries," http://www.bloomberg.com/slideshow/2013-02-01/50-most-innovative-countries.html - slide50.

[23] S. Chung, "Innovation, Competitiveness and Growth: Korean Experiences," Science and Technology Policy Institute (STPEI), 2011.

[24] B. Jaruzelski, J. Loehr, and R. Holman, "The 2012 Global Innovation 1000: Key Findings," Booz & Company, 2012, http://www.booz.com/media/file/BoozCo_The-2012-Global-Innovation-1000-Media-Report.pdf.

[25] A. Taylor, K. Wagner, and H. Zablit, "The Most Innovative Companies 2012: The State of the Art in Leading Industries," BCG Perspectives, January 10, 2013.

Samsung's control of the entire process from design, to manufacture, to fulfilling customer orders gives them this edge.[26]

Mixed Success

Brazil, Russia, and South Korea have leveraged their endowments with mixed success. The common themes across these three countries are the development of large, often world-class, companies based on their endowments and the presence of manufacturing capacity (a major source of innovation in developed countries). They have achieved their current innovation state through top-down, state-led policies. Their common challenges are to continue to develop the slowly emerging linkages between universities and firms that support the development of small- and medium-sized technology-oriented companies. Each country has implemented policies and incentives to encourage more collaborations and startups. The challenges for these small companies are the lack of access to capital and maneuvering a bureaucratic system.

In many cases, a country's strengths can also be the source of their challenges or weaknesses. South Korea is the most successful of the three in terms of rapid economic growth. Their *chaebols* are successful in rapidly anticipating demand (a strength) but make it difficult for small companies to compete. Brazil's innovation policies are leading to the development of new entrepreneurial companies, but many small companies still face a high cost of doing business and so often remain in the informal economy. Despite enacting legislation to promote innovation, Russia's strongly top-down system is not conducive to innovation. A growing middle class, however, is likely over time to demand innovation, and there are glimmers of changes already occurring in Russia as businesses learn from the U.S. and Europe. Brazil and Russia also need to invest in infrastructure to assure innovation capabilities for development.

Lessons for all countries—gleaned from examining the innovation policies of these three countries—are that top-down, state-driven policies can lead to development of world-class companies and manufacturing capacity. However, these state-driven economies must transition to developing bottom-up linkages across industry, university, and government. Top-down policies with bottom-up incentives will accelerate the translation of inventions to innovation to move new products, processes, and services to the market. The challenge for each country is adapting their policies so firms can fully leverage their endowments.

While there is no generic blueprint for national innovation, there are common characteristics that each country can emphasize. They include developing linkages between universities and companies and creating clusters in specific technical areas that facilitate the flow of ideas and create core competencies that spill over across the cluster. Other characteristics are spending a high share of private and public spending on R&D (about 3 percent of GDP), ensuring that startups and small companies have access to capital, building infrastructure, (transportation, communications, information technology, and other), and reducing bureaucracy to facilitate the conduct of business.

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[26] A manufacturing supply chain encompasses many steps to complete a customer request. The supply chain includes not only the manufacturer and suppliers but also transporters, warehouses, retailers, and customers themselves. The functions include new product development, marketing, operations, distribution, finance, and customer service. See Sunil Chopra and Peter Meindl, *Supply Chain Management*, 2nd ed., (Upper Saddle River, NJ: Pearson Prentice Hall, 2004).

In Conclusion: Technology, Power, and the Limits of Governance

by Zachary Davis and Michael Nacht

Now is the dramatic moment of fate, Watson, when you hear a step upon the stair which is walking into your life, and you know not whether for good or ill.—Arthur Conan Doyle

The term strategic latency describes the potential for technology to be harnessed to the plow of human desires. The connection between technology and power has always been strong, but it appears to be growing stronger for reasons that are explored in this book. We use the term "strategic" to describe potentially world-changing effects. The "latent" aspect arises when people figure out how to transform scientific ideas into usable forms of power, which can occur quickly or latent potential can lay dormant until someone taps into previously unrecognized possibilities.

Discoveries of latent potential are motivated by the full spectrum of individual and collective intentions, from altruism to scholarly inquiry to evil, and they are often the result of unintended consequences, accidents, and human folly. This book attempts to establish a framework for thinking about the ways that technology can be exploited to fulfill the hopes and dreams of mankind on the modern era. We consider the increasingly multidisciplinary and interdisciplinary nature of modern science and the increasingly complex political–economic drivers that transform ideas into action. In this way, we offer a holistic approach for understanding how technology is changing the way we think about national and international security.

Our chapters explore the transformation of scientific concepts into economic, political, and military forms of power. The authors align themselves along the spectrum of constructive and malevolent possibilities, ranging from Banning Garrett's optimistic outlook for the future of additive manufacturing to Davis' darker assessment of battlefield applications for emerging technologies. Case studies of currently unfolding strategic latency for lasers by Bob Yamamoto and robotics by Robert Manning describe how latent potential is being harvested for these technologies and how market forces can make or break promising ideas. In practice, latent potential unfolds in fits and starts as technologies surge ahead when conditions align or fizzle out until circumstances become more favorable. By addressing the factors that underlie how particular technologies ebb and flow, Richard Silberglitt outlines foresight methods that illuminate technology trends and give us a peek at the future, yet do not overpromise guaranteed outcomes. Even with "big data" sets to crunch with ever-increasing computing power, predicting the future of technology suffers from similar uncertainties as predicting the weather or the outcomes of sporting events. Surprise is inevitable.

Studying the relationship between technology and security is, of course, nothing new. Generations of science fiction writers, scholars, ethicists, and activists have analyzed how technology affects societies. From Orwell's thought police, to the atomic bomb, to recent concerns about cyber espionage and privacy, technology has penetrated every nook and cranny of our individual and collective existence. Globalization has supercharged the rate of technological change and accelerated the transition of ideas into products. With the global pervasiveness of technology has come a growing convergence and interdependence of formerly distinct fields of study. Old distinctions among physics, chemistry, biology, and computer science have blurred, and hybrid fields have emerged (synthetic biology, for example). Computations, modeling, and simulation have become essential for dealing with the complexity that results from a rapidly accumulating tsunami of information. Even the so-called "soft" sciences of economics, international relations, history, and sociology are increasingly essential to a comprehensive analysis of the effects of technology on global security. As Ron Lehman, the intellectual godfather of strategic latency, points out in the first chapter:

The advancement and wider accumulation of dual-use technology is worthy of study itself. In bringing together such different perspectives as military intelligence, nuclear safeguards, bio-security, export controls, arms control, disarmament, verification, *information technology, cyber operations, innovation economics, business management, foreign trade, intellectual property law, investment strategies, science culture, education, development, and ethics, we may not only gain new insights into each of those fields, but we may obtain transcendent insight into the dynamics of the contemporary world.*

In practice, this convergence means that multidisciplinary teams of specialists offer our best hope for understanding how technology is shaping the security environment. Such an understanding is particularly important for policymakers who bear responsibility for national defense and security matters, but this understanding is also required for anyone seeking an informed view of the world today. In our discussions of strategic latency, we attempt to embrace the complexity that has become a central feature of the intersection of S&T and world politics.

Several authors make the case that nation-states no longer control world-changing technologies as they once did. Joe Pilat describes the "born secret" history of nuclear technology and the relative successes of the institutions that were established to separate the military and civilian uses of atomic energy. In this case, latency was controlled. Such controls are no longer feasible. To the contrary, the diffusion of knowledge has placed cutting-edge technological latency in the hands of private groups and individuals. This trend is best illustrated by the do-it-yourself (DIY) movement—a loose knit network dedicated to the empowerment of individualized design and production of everything from drones to body parts. Easy access to the latest knowledge, materials, and tools enables hobbyists to wield powerful technologies that were once the exclusive domain of governments, universities, and major research institutions. Adding to concerns that scientists could create new and possibly dangerous life forms—illustrated by the debate over whether to publish research on the H5N1 bird flu virus[1]—amateur biologists are capable of increasingly sophisticated and largely unregulated experiments.[2] Classroom laser pointers have become a potential threat to aviation, 3D printers can manufacture guns, and teenagers are among the world's leading cyber hackers. For better and for worse, the democratic diffusion of technology is unstoppable. While individual citizens and DIY clubs might make valuable contributions to society, the risks posed by high-tech "Unabombers" and tech-savvy doomsday cults are also growing. People, not governments, increasingly will decide whether to exploit the latent potential of technology for good or evil purposes.

And yet, the country case studies of national S&T policies demonstrate the continuing role of governments in the development and exploitation of technology. Research and development (R&D) is an essential link in the discovery of latent potential and the transformation of scientific ideas into useful products. In their chapter on Brazil, Russia, and South Korea, Stephanie Shipp and Nayanee Gupta chronicle national efforts to stimulate S&T progress. They observe how the mixed results of those efforts are rooted in a complex mix of cultural and organizational factors. Drawing upon his studies of China's S&T policies, Tai Ming Cheung draws a parallel between China's national latency as a world power and Beijing's efforts to accelerate its rise though S&T investments. Can China leap-frog ahead to lead the world in S&T? Carolyn Chu and Michael Nacht explore Japan's tremendous technological latency and speculate on the prospects for its continued restraint in translating such latency into military capabilities. Zev Winkelman and Nacht then document Turkey's steady accumulation of advanced S&T latency and analyze its potential contributions to Turkey's rising regional and international status. In sum, governments have not given up trying to cultivate S&T as a source of national power. To the contrary, they are accelerating and intensifying their efforts.

In fact, recent scholarship by Marina Mazzucato demonstrates how hundreds of billions in government R&D funding laid the foundation for the modern biotech, aerospace, energy, and computer industries,

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1 Gigi Gronvall, "H5N1: A Case Study for Dual-Use Research," Council on Foreign Relations Working Paper, July 2013.

2 "Amateurs are New Fear in Creating Mutant Virus," *New York Times*, March 5, 2012; and "Hacking the President's DNA," *The Atlantic*, November 2012.

which were then able to generate trillions in profits. While entrepreneurs and venture capitalists claim credit for the latest drugs, electronics, or weapon systems to hit the market, their successes are built on years of taxpayer investment in the fundamental research that cultivated the S&T latency from which sprang immense wealth and prosperity.[3] Private companies, she observes, "have 'surfed the wave' rather than created it."[4] Now, other countries are seeking to recreate a similar synergy between the public and private sectors by investing in S&T. As global competition for high-tech advantage intensifies, cutbacks in U.S. public and private sector funding for basic research risks killing the "golden goose" that spawned America's post-World War II dominance.[5] Challenges facing the U.S. education system, especially in science, technology, engineering, and mathematics (STEM), threatens U.S. competitiveness, particularly when compared to the countries that are investing heavily in these areas.[6]

The country case studies in this volume confirm the importance of national policies and resources for the advancement of the basic science that makes economic innovation possible. Even without guarantees of tangible military or economic payoffs, strong countries cannot afford to be left behind while others find ways to transform technology into economic, political, and military power. Strategic latency is the wellspring from which "hard" and "soft" power is drawn.[7] National interests remain a primary motivator for S&T innovation and exploitation.

Good Versus Evil?

Technological progress has merely provided us with more efficient means for going backwards.—Aldous Huxley

Our expectations for strategic latency are inextricably linked to our concepts of human nature, leading individuals and societies to develop and use technology to pursue both peaceful and aggressive purposes.

Some pessimists emphasize the harm done as countries, groups, and individuals turn technology against their neighbors in pursuit of personal and national ambitions. From this perspective, states, terrorists, and antisocial individuals should be expected to exploit technology to serve their aggressive tendencies. In such a technology-fueled Hobbesian "state of nature," all community members are forced to acquire defensive capabilities or risk subjugation. Without a Leviathan to restrain the military applications and oversee the distribution of the benefits of emerging technologies, strategic latency will simply channel the power-seeking urges that explain human conflict among individuals, groups, and nation-states throughout the course of human history. To paraphrase Thucydides, the powerful will reap the spoils of S&T largesse, while the weak will "suffer what they must," and strategic latency will remain little more than a stage on which to play out the age-old competition for economic, political, and military advantage. In other words, expect the worst.

On the other end of the spectrum, some techno-optimists such as Peter Diamandis embrace technology as a savior that offers solutions to many of the most vexing problems facing mankind.[8] As knowledge accumulates and our ability to rapidly probe massive data sets accelerates, the ability to devise technological remedies to social ills—especially those rooted in material scarcity—will skyrocket. Moore's

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[3] Mariana Mazzucato, *The Entrepreneurial State*: *Debunking Public vs. Private Sector Myths* (London: Anthem Press, 2013).

[4] Ibid., 69.

[5] "The Sequester is Going to Devastate U.S. Science Research for Decades," *The Atlantic*, March 12, 2013.

[6] *S&T Strategies of Six Countries* (Washington D.C.: National Academies Press, 2013).

[7] Joseph Nye Jr., *Soft Power: The Means To Success In World Politics* (Cambridge: Perseus Books, 2004).

[8] Peter Diamandis and Steven Kotler, *Abundance: The Future is Better Than You Think* (New York: Free Press, 2012)

Law, which ambitiously predicted the rapid pace of technological discovery, proved far too conservative. Even the futurists could not have anticipated the current rate of technological progress. Armed with this mother lode of technology and expanding analytic capacity, people will create technologies to provide the world with ample food, clean water, fantastic medicines, speedy transportation, and limitless supplies of clean energy. From this perspective, all problems are tractable because technological solutions are increasingly within reach. With competition for resources removed as a primary motivation for behavior, these optimists argue that conflict will be greatly reduced and global society can turn its attentions to peaceful, productive, and creative pursuits. Released from the pressures of survival and security, the "noble savages" will be free to enjoy the blessings of civil society. For the optimists, the benefits of technological latency will greatly outweigh the negative security consequences. Undaunted by the challenges, they say, "Bring it on!"

Which side of human nature will prevail? Neither pessimists nor optimists are likely to be disappointed. The full span of human motivations will be on display in the exploitation of strategic latency. It should come as no surprise, therefore, that the adult entertainment industry has been a leading technology innovator, pioneering new frontiers in streaming video and online payments,[9] and terrorists are among the chief innovators of new destructive methods.[10] Technology will bring vast improvements in the human condition while it simultaneously creates new perils, influencing but not replacing deeply ingrained behaviors.

It is not the fault of technology if we "go backwards," as Huxley feared, nor is technology prodding us forward as imagined by former *Wired Magazine* editor Kevin Kelly, who believes that "humans are the reproductive organs of technology."[11] Technology is neither pushing nor pulling mankind toward any destiny that is not firmly rooted in our free will.

Global Governance: Who's In Charge?

Who will determine the winners and losers in the hunt for technological advantage? If individuals, groups, and nation states are unwilling and/or incapable of managing the effects of technology on the global commons, who is in charge? In his recent book, Moisés Naim describes the ultimate diffusion of power and its attendant problems of governance.[12] Centralized authority has eroded everywhere—in churches, corporations, and nations. In such a world, the prospects for building powerful new governance structures to oversee the economic and military consequences of emerging technology are not good. Creating new multilateral norms and institutions similar to the ones that were established in the post-World War II era to manage nuclear, chemical, and biological technologies appears unlikely. Ongoing efforts to establish international rules for climate change, cyber warfare, and space weapons have, so far at least, not been encouraging. Many developing countries view such efforts as a ploy by the rich to perpetuate their dominance, and even the current technological leaders are hesitant to offer rules that limit their own options. New conventions to regulate the uses of emerging technologies face an uphill battle. Powerful incentives would be required to attract adherents.

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[9] "Porn: The Hidden Engine That Drives Innovation in Tech," *Business Insider*, July 5, 2013, http://www.businessinsider.com/how-porn-drives-innovation-in-tech-2013-7, accessed September 4, 2013.

[10] Maria Rasmussen and Mohammed Hafez, "Terrorist Innovations In Weapons of Mass Effect," Naval Postgraduate School, Center for Contemporary Conflict, August 2010, http://www.nps.edu/Academics/Centers/CCC/Research/Terrorist_WME_Spotlight_2010-12.html

[11] Kevin Kelly, *What Technology Wants* (New York: Viking Press, 2010).

[12] Moisés Naim, *The End of Power: From Boardrooms to Battlefields and Churches to States, Why Being In Charge Isn't What It Used to Be* (New York: Basic Books, 2013).

Poor nations might be more inclined to support new norms if, in return, they can gain access to the benefits of new technologies that would not otherwise be available to them. This approach was a key element of the "nuclear bargain" that was built into the Nuclear Non-Proliferation Treaty. Nations were guaranteed access to nuclear technology on the condition that they would promise not to use the technology for military purposes, *and* that they would allow inspections to ensure they abide by their agreement. A similar approach might help persuade developing countries to support rules against the misuse of emerging and potentially dangerous technologies such as nanostructures, synthetic biology, space, or geoengineering techniques. However, as noted earlier, national governments no longer control the knowledge, materials, and uses of technology as they once did and may not even be aware of research and manufacturing taking place within their own borders.

Criminal networks are already adept at hiding illicit activities behind legitimate trade and avoiding detection, especially in ungoverned or poorly governed regions. The weakness of national control over territory, made even more daunting by undeclared and innocuous-looking S&T activities, combined with corporate security measures to protect trade secrets, makes inspections highly problematic and undermines confidence that rules are being followed. These problems are evident in the Biological Weapons Convention, which only prohibits "offensive" capabilities and does not include inspections. Fuzzy definitions of what is prohibited, the lack of effective inspection protocols, and dim prospects for international enforcement of violations cast serious doubt on the prospects for new multilateral conventions to control technology in any meaningful fashion.

Despite these shortcomings, efforts to establish rules and norms to guide the uses of emerging technology still have merit. Perpetuating standards of conduct, exchanging best practices, promoting transparency, and maintaining interactions with people and institutions working on potentially dangerous R&D can warn researchers about possible risks and alert authorities to signs of misconduct.[13] Multilateral and bilateral agreements can provide conduits for assistance to help developing nations reduce the risk of accidents and establish effective monitoring and oversight systems, much as the cooperative threat reduction programs helped former Soviet states cope with orphaned weapons of mass destruction (WMD) stockpiles and redirect scientists toward nonmilitary research topics. Similarly, the Proliferation Security Initiative—a nonbinding, voluntary "coalition of the willing"—established an international forum for governments to share and practice WMD interdiction techniques.[14] Scientific exchanges focused on best practices for emerging technologies can support the development of globally recognized norms and standards to guide R&D in areas that are heavily latent with military potential. However, such openness may be more acceptable for basic scientific research than for applied sciences. Private companies working on innovative approaches depend on secrecy to protect intellectual property and proprietary information. For them, transparency and openness involve considerable risks with few benefits. Nevertheless, even without formal treaty obligations, international cooperation can serve a valuable, albeit limited, purpose.

Unless compelled to do so, or lured by the prospect of tangible benefits, countries, groups, or individuals are not likely to risk promising economic or military potential to satisfy international preferences. The most we can expect, at least for the foreseeable future, is a web of voluntary, inconsistently applied, and heterogeneous cooperation efforts for basic scientific research topics. Such efforts are likely to be championed by concerned nations and responsible scientists but viewed skeptically by have-nots unless they are accompanied by powerful inducements. Applied research, especially in areas with high potential

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[13] See, for example, S. Maurer and S. V. Engelhardt, "Industry Self-Governance: A New Way to Manage Dangerous Technologies," *Bulletin of the Atomic Scientists*, May 2013.

[14] "Proliferation Security Initiative, Statement of Principles," White House Fact Sheet, September 4, 2003, http://www.state.gov/t/isn/c27726.htm

for military and economic advantage, will remain conducted mostly behind closed doors, governed by the nations, companies, and individuals who discover, sponsor, develop, and control such activities.

Caution, Latency Ahead

Necessity is the mother of invention.—Plato

With so much uncertainty about which technologies will reveal game-changing strategic latency, how such latency might be deployed, and by whom, several major trends are nonetheless evident.

First, technology is moving forward at an accelerated pace, bringing with it unknown but far-reaching effects on the concept of security at every level of social organization. Strategic latency is here to stay. As a result, governments and substate actors will be forced to devote more resources to understanding, reacting to, and exploiting an expanding array of emerging and disruptive technologies. The effects will be pervasive—on the battlefield, in the marketplace, in politics, throughout the environment, and in our personal lives. Some nations are preparing to meet the challenge but most are not. Bernard Baruch, the author of the 1946 American plan for international control of atomic energy, may have overstated the case in his speech to the United Nations when he warned that "we are here today to make a choice between the quick and the dead,"[15] but he was correct that the world had reached an important milestone brought about by the effects of a new technology. We should not be surprised if the latent technologies of today bring changes of a similar magnitude tomorrow.

A second visible trend is that the positive benefits foreseen by the techno-optimists are equally evident with game-changing potential. Real strides against poverty and disease will improve the human condition and might create the conditions for systemic change in the international system. A more equitable distribution of technology-derived power achieved through cooperative mechanisms could conceivably bear the seeds of a nascent "liberal-institutionalist" world order, as suggested by Richard Silberglitt in his chapter. Under the right conditions, the better angels of strategic latency could dominate, and violence could eventually subside as a way of settling conflicts. Another possibility, however, is that the healthy citizens happily working in technologically advanced, clean, and efficient democratic societies might not share the wealth and might even harbor animosities toward foreign peoples. The benefactors of technological latency might tap the same technologies that elevated their living conditions to gain further advantage over others. Even amidst material abundance, economic competition would still produce winners and losers, and criminals would still break laws to acquire ill-gotten gains. Imbalances of power would lead to balancing behaviors, and familiar patterns of international politics would persist. There will be vast improvements in the struggle for survival, but they come with no guarantee of radical changes in human nature. The growing complexity and chaos of our technological future will not necessarily lead—and in our view are unlikely to lead—to revolutions in the way that individuals, groups and societies interact with one another.

A third and related trend is the *de minimis* role of governance in the development, exploitation, and uses of new technology. Techno-optimists and liberal institutionalists are correct that national governments have lost control over many aspects of international life, and a multitude of nonstate actors have filled the void.[16] However, the corresponding dissolution of power and resulting challenges of governance described

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[15] Bernard Baruch, "Statement of United States Policy," presented to the United Nations Atomic Energy Commission, June 14, 1946, http://www.atomicarchive.com/Docs/Deterrence/BaruchPlan.shtml.

[16] See Ayesha and Parag Khanna, "Hybrid Reality: Thriving in the Human-Technology Civilization" (TED books), http://hybridreality.me/hybrid-reality-thriving-in-the-emerging-human-technology-civilization/.

by Moisés Naim are unlikely to result in a new and widely accepted political order to control dangerous technologies. Globalization is making concentrations of power that are necessary for basic governance more difficult. State, local, national, multilateral, and fraternal systems of governance can set standards and facilitate shared norms, but they can do so only where and when the interests of their constituencies are compatible. Strategic latency represents potential sources of power that, most likely, will follow the traditional conventions of power politics.

Technology is a crucial variable that is changing the way we think about security. Its influence, already great, is accelerating. Human nature, however, is the key independent variable. Technology is a tool that humans use to achieve their objectives—a means to an end. In strategic latency, we can see powerful new tools in the making, and we need to think persistently and systematically about how they might be used. The core lesson from this study is that such effort is now essential to protect our vital national interests.

Author Biographies

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