

IN SEARCH OF STRATEGIC ADVANTAGE: UNDERSTANDING THE LANDSCAPE OF TECHNOLOGY COMPETITION

KIMBERLY PEH AND MICHAEL ALBERTSON, EDITORS



Center for Global Security Research
Lawrence Livermore National Laboratory
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Preface

Michael Albertson

In an era of seemingly ever-increasing global tensions, technology competition is often mentioned as a pathway for U.S. and allied success. The opening arguments are often very simple. “This is the most important struggle of the 21st century.” “We cannot afford to lose this competition.” “The United States must not fall behind in this race.” “We must be faster, more agile, more committed, more thoughtful than our competitors.” Competition around a particular technology is described as a once in a generational struggle with immense stakes. “This is a Sputnik moment” is a common analogy.

The solutions proposed are fairly straightforward—more of everything. We should spend more money. We should build more widgets or more factories. We should innovate more. We should focus more. We should attract more talent. We should file more patents. We should produce more PhDs. If we do more of everything, we will have more technology than our opponents, they will see our technological advantage, they will not challenge us, and therefore we will win. If we fail to do these things, we will lose. To paraphrase Homer Simpson, in national security policy discussions technology competition has become the cause of, and solution to, all of life’s problems.

And yet, beyond doing more across the board, understanding technology competition and prescribing approaches are not at all simple. First, it is a concept increasingly muddled together with other big issues such as innovation policy, national defense strategy, great power competition, allied cooperation, public-private partnerships, and a host of other issues. Certain policies, systems, coalitions, and so on may be excellent for tackling one challenge, but far less optimal for others. Second, it is inherently dynamic, an action-reaction cycle between multiple players. A brilliant opening move can be squandered or successfully countered in subsequent moves. Third, there are limits to what you can do—limited time, limited financial resources, limited human capital, and limited knowledge of what lies ahead. One is forced to choose.

These complexities raise hard yet basic second-order questions. What exactly are the stakes we are competing over? What are the benefits and costs of being ahead or behind? How do we accurately measure who is ahead or behind? What does “winning” look like? Where is the finish line to define when one has “won” the competition? What are the advantages to being a first mover, or a second mover, on a technology? What role do factors like national leadership, national industrial policy, public-private partnerships, government systems, and so on play in a successful technology competition? Do we compete with allies? Do we cooperate with adversaries? What should we choose to focus our attention on, at the risk of falling behind somewhere else? How do we translate some technological advantage into an economic or military advantage to achieve some concrete national security goal? These are very hard questions to answer. With notable exceptions from a few gifted authors, several of whom have presented in the CGSR lecture series and workshops over the last two years on these topics, technology competition is very hard to tackle holistically across all technologies and all competitive dynamics when done by a single author.

Rather than rely on one person, what this volume has tried to do is to pull together a group of talented writers drawn from CGSR experts, the postdoctoral cohort co-sponsored by LLNL, LANL, and the University of California, and other LLNL staff to tackle various parts of the technology competition topic from their different perspectives, in the hopes that the whole of the chapters and thus the readers' conclusions can add up to more than the sum of the parts.

The authors look at different dimensions of the problem, but they often end up reinforcing and referencing each other's work. Some of the authors look at dyadic competitions between states. Some explore the dynamics of technology competition between allies or between adversaries. Others look at a particular technological competition in fields like nuclear weapons, energy security, or quantum computing. Some look at mechanisms for competing, such as export controls, or mechanisms for assessing and testing the competition, such as net assessments and wargaming. But many of the questions and problems are the same throughout the work. These are hard fundamental questions about how technology competition works and what we should focus on.

One of the key unifying concepts that the reader will see interwoven into these chapters is the idea of "strategic advantage," a term frequently mentioned but less frequently defined in key articles and national security documents. One of course does not want to be at a strategic disadvantage in a technology competition, but defining what strategic advantage is and where it can be used is more challenging. If resources are finite, where should they best be spent to achieve advantage? How do you measure advantage, either in scale or duration? What is the role of competitors and partners in gaining or losing a strategic advantage? If outright winning a technology competition is impossible, how should one get ahead and leverage being advantaged to best use? These are questions for the United States and its allies more generally, but for the national laboratories more specifically, to understand and explore.

I thank the authors for their intellectual contributions to the topic, Dr. Kimberly Peh for her leadership and help in putting this volume together, and the reader for taking the time to explore this challenging area along with us.

Technology Competition and Arms Racing in U.S. Nuclear Weapons Policy

Anna Péczeli

Introduction

After the end of the Cold War, the United States took a leadership role in reducing nuclear dangers by limiting the role of nuclear weapons in U.S. national security strategy, implementing dramatic reductions in U.S. nuclear forces, and promoting global efforts to advance nonproliferation, arms control, and nuclear security. However, all these pillars of cooperative security face significant challenges today. Over the past decade, geopolitical rivalry has intensified, and nuclear dangers have dramatically increased. Russia, China, and North Korea are all expanding and diversifying their nuclear arsenals, while arms control mechanisms have crumbled, and there is little hope that they will be replaced. U.S. adversaries have openly expressed their desire to undermine the rules-based international order and remake the global balance of power in their favor.¹ In light of these developments, there is a growing number of analysts that talk about a new nuclear arms race.²

Our understanding of a nuclear arms race is largely informed by the Cold War experience. In the 1950s and 1960s, the United States and the Soviet Union were engaged in an intense nuclear arms race that had many distinct characteristics. In this paper, I compare these characteristics with the main trends in the current security environment and argue that what we see today is not a new nuclear arms race, but an intensifying technology competition with 21st century characteristics.

Since the beginning of the nuclear era, technology competition has been a standard feature of great power relations, and it has played an influential role in the development and proliferation of nuclear weapons. However, technology competition and arms racing are not the same concepts. Technology competition has traditionally been an important aspect of arms races, but these two can also occur without each other. Technology competition can take place without triggering an arms race, and an arms race might continue even if the technology competition is halted for any reason.

During the Cold War period, there was a positive feedback loop between technology competition and arms race dynamics—technology competition opened new areas in arms racing between the United States and the Soviet Union, while the demands of the ongoing arms race fueled the competition in nuclear technologies. The reason why these terms are often confused or used

1 Brad Roberts, “The Next Chapter in U.S. Nuclear Policy,” *The Washington Quarterly* 47, no. 2 (2024), pp. 7–21.

2 See for example, United Nations, “Nuclear Arms Race ‘Heading in Wrong Direction,’ United Nations Chief Warns, as General Assembly Marks Day for Their Total Elimination,” High-Level Meeting on Elimination of Nuclear Weapons (September 26, 2024). <https://press.un.org/en/2024/ga12636.doc.htm> (accessed February 9, 2025); Geoff Wilson, “Trump, the United States, and the New Nuclear Arms Race,” *Arms Control Today* 54, no. 10 (2024), <https://www.armscontrol.org/act/2024-12/features/trump-regain-control-us-nuclear-policy-now-what> (accessed February 9, 2025); Jessica T. Mathews, “A new nuclear arms race is beginning. It will be far more dangerous than the last one,” *The Guardian* (November 14, 2024), <https://www.theguardian.com/world/2024/nov/14/nuclear-weapons-war-new-arms-race-russia-china-us> (accessed February 9, 2025); “America prepares for a new nuclear arms race,” *The Economist* (August 12, 2024), <https://www.economist.com/united-states/2024/08/12/america-prepares-for-a-new-nuclear-arms-race> (accessed February 9, 2025); and Paul Dibb, “A new U.S., Russia, China nuclear arms race spells danger,” Australian Strategic Policy Institute (August 16, 2024), <https://www.aspistrategist.org.au/a-new-us-russia-china-nuclear-arms-race-spells-danger/> (accessed February 9, 2025).

interchangeably is that they were so closely intertwined in the Cold War years. Both concepts were driven by the same deterrence requirements, thus they shared many of the same objectives—developing more powerful, more useable, more sophisticated, and more survivable nuclear weapons. At the same time, their underlying logic was different in important ways. The nuclear arms race was generally seen as a zero-sum game, where one side's gain was the loss of the other side which often triggered some kind of reaction. The ultimate goal was to gain some form of military advantage to deter (and if necessary, defeat) adversaries.

Technology competition, on the other hand, does not automatically imply a zero-sum logic. The primary goal here is innovation and the development of new capabilities to support specific national security objectives. These objectives generally entail much broader goals than simply deterring or defeating adversaries. They can, for example, include developing safer weapons that are less prone to accidents or implementing safeguards that can help to prevent unauthorized use of these weapons. These objectives are not always zero-sum and very often reciprocal measures by an adversary are desirable. Thus, technology competition is not in conflict with the notion of cooperation, and certain scientific achievements can be beneficial for all parties. This is why technology competition endured even when geopolitical relations were not antagonistic.

The aim of this analysis is twofold. First, I intend to show how arms race dynamics and technology competition relate to each other. While they are rooted in the same deterrence requirements, and technology competition is an important element of most arms races, they also differ in fundamental ways. Second, I intend to explore how the competitive dynamics in the current environment are different from the Cold War and what policy implications arise from these differences.

With regard to the subject of analysis, since military doctrines and employment strategies consider nuclear weapons inseparable from their delivery platforms, I apply a holistic approach to competition in nuclear weapons. Thus, advancements in nuclear warhead designs, the overall nuclear weapons complex, and developments in delivery platforms are all taken into account as I analyze the evolution of these competitive dynamics.

There are two main chapters in this paper. The first one analyzes the Cold War competition and the second one focuses on the current security environment. Both chapters have the same structure. Each starts with an overview of the deterrence requirements and the main areas of competition. Then the chapters proceed with a deep dive into the key trends in arms race dynamics and technology competition, which demonstrates not only important connections, but also some key differences between them. The final two chapters provide a summary of the key takeaways from this comparison and outline the most important policy implications for the United States.

Technology Competition and Arms Racing in the Cold War

Deterrence Requirements and the Main Areas of Competition

The essence of nuclear deterrence is that an adversary is discouraged from attacking due to the threat of retaliation that would cause unacceptable damage. This theory goes all the way back to 1946 when Bernard Brodie argued in *The Absolute Weapon* that nuclear weapons fundamentally change warfare and in the nuclear age wars should be averted.³ He believed that the key to avoiding these

3 Bernard Brodie, ed., *The Absolute Weapon: Atomic Power and World Order* (New York, NY: Harcourt Brace, 1946).

wars was to acquire the ability to retaliate in kind and “to explore all conceivable situations when the aggressor’s fear of retaliation will be at a minimum and to seek to eliminate them.”⁴ His theory put the emphasis on the importance of a secure second-strike capability, while arguing against a surprise first attack on the basis that “If the aggressor state must fear retaliation, it will know that even if it is the victor it will suffer a degree of physical destruction incomparably greater than that suffered by any defeated nation of history ... Under those circumstances no victory, even if guaranteed in advance—which it never is—would be worth the price.”⁵

In contrast with these views, William Borden’s 1946 book *There Will Be No Time* argued that nuclear weapons will soon spread to U.S. adversaries and nuclear war will be very difficult to avoid. In his view, the best way to win such a war was to use nuclear weapons to disarm the opponent and to destroy its retaliatory power. Unlike Brodie, Borden thought that a surprise attack on adversary nuclear forces was the best way to avoid a devastating retaliation.⁶ The main implication of this line of argument was that vulnerabilities in the nuclear age can be incredibly dangerous, because states will have a strong motivation to launch a preemptive attack on the nuclear forces of their (less advanced) adversaries. Thus, Borden argued in favor of prioritizing a nuclear buildup in the United States that should include forces for rapid, rocket-based nuclear strikes.

These early works highlighted the importance of a secure second-strike capability and the dangers of vulnerability. These two dilemmas have dominated strategic thinking⁷ throughout the Cold War, and they also had a profound effect on technology competition in the nuclear age. Accordingly, deterrence requirements were driving two key lines of effort: building a nuclear arsenal that can survive a first strike (*survivability*) and developing capabilities that can effectively retaliate or preempt (*reliability*).

After the Soviet Union conducted its first nuclear test, the threat of a surprise attack became a central issue in the United States.⁸ Given the recognition that improving the survivability of U.S. nuclear forces was going to take time, temporary fixes were implemented that included getting bombers off the ground and preparing to launch nuclear weapons first in the face of an impending Soviet attack. The concept of preemption was embraced by the Eisenhower administration because it was seen as the most effective way to defend the North Atlantic Treaty Organization (NATO) allies

4 Ibid., p. 77.

5 Ibid., p. 74.

6 William L. Borden, *There will be no Time: The Revolution in Strategy* (New York, NY: Macmillan Co., 1946).

7 See more about this in Michael S. Gerson and Elbridge A. Colby, eds., *Strategic Stability: Contending Interpretations* (Carlisle Barracks, PA: U.S. Army War College Press, 2013), pp. 1–37.

8 Official government documents [such as National Security Council Report 68 (NSC-68) and NSC-162/2] expressed serious concerns about the Soviet capacity to inflict critical damage on the United States and undermine its ability to retaliate with atomic weapons. A U.S. Air Force study conducted by RAND Corporation researcher Albert Wohlstetter arrived at similar conclusions, arguing that U.S. bombers at bases in Europe and the continental United States could be destroyed on the ground by a Soviet preemptive attack, which would be a devastating blow to U.S. nuclear deterrence. “NSC-68,” Office of the Historian, U.S. Department of State (1950), <https://history.state.gov/milestones/1945-1952/NSC68> (accessed February 9, 2025); “NSC 162/2 – Report to the National Security Council by the Executive Secretary,” Office of the Historian, U.S. Department of State (1953), <https://history.state.gov/historicaldocuments/frus1952-54v02p1/d101> (accessed February 9, 2025); Albert Wohlstetter, “The Delicate Balance of Terror,” RAND Corporation (1958), <https://www.rand.org/pubs/papers/P1472.html> (accessed February 9, 2025).

against the conventionally superior Warsaw Pact, and because it was a necessity to address the vulnerability of the U.S. bomber force.⁹

However, as the U.S. nuclear arsenal became more diverse, new solutions were needed. Subsequent efforts to increase survivability applied three basic approaches: hardening, concealment, and redundancy. Hardening included efforts to deploy missiles in reinforced silos that were designed to withstand the effects of nuclear detonations, such as blast, heat, and ground shock; placing bombers in reinforced shelters; creating protective sites for mobile missile launcher patrols; burying command and control (C2) sites; and securing communication of launch orders. Concealment was the primary foundation of survivability for mobile systems, such as ballistic missile submarines (SSBNs) that had the option to hide in vast deployment areas. Lastly, using redundancy to improve survivability was a key element in every aspect of nuclear operations from delivery platforms and warhead designs to C2 systems and early warning assets. These redundancies helped to complicate adversary strike plans, and they also helped to protect against unforeseen technological failures.¹⁰

Deterrence requirements also triggered intense technology competition in reliability, which meant the ability to reach a target and effectively destroy it. These objectives had important implications for accuracy, yield requirements, and deployment options. In terms of accuracy, bombers and ballistic missiles faced many challenges. During most of the Cold War period, these systems were not accurate enough to reliably destroy hardened targets. Gradual improvements in navigation and guidance from the 1970s have started to increase the ability of missiles to determine their position in flight and guide themselves to target. As a result, from the mid-1980s, the newly deployed missile systems had significantly improved accuracy that posed a real threat to hardened targets.¹¹

Regarding yield requirements, in the early years of the Cold War the U.S. arsenal included a large variety of shorter-range, lower-yield, nonstrategic weapons that were developed to counterbalance the conventional advantages of the Warsaw Pact in Europe. After 1967, however, U.S. priorities shifted, and the United States refocused its attention on strategic systems. As missiles were more expensive than warheads, priority was given to nuclear weapons with high yield-to-weight ratios and there was a strong impetus to develop the ability to deploy Multiple Independently Targetable Reentry Vehicles (MIRVs) that carried multiple warheads on a single missile. These developments were coupled with enhanced military performance characteristics, such as selectable yields and greater accuracy of delivery platforms. As a result of these new trends, the United States has dramatically reduced its non-strategic nuclear arsenal.¹²

Lastly, increased reliability also had implications for deployment modes. For example, mobility and range requirements made it necessary to relocate certain U.S. nuclear capabilities and deploy

9 Gerson and Colby, eds., *Strategic Stability: Contending Interpretations*, pp. 1–37.

10 Keir A. Lieber and Daryl G. Press, “The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence,” *International Security* 41, no. 4 (2017), pp. 16–17; Austin Long and Brendan Rittenhouse Green, “Stalking the Secure Second Strike: Intelligence, Counterforce, and Nuclear Strategy,” *Journal of Strategic Studies* 38, no. 1–2 (2015), pp. 38–73.

11 See more about this in Lieber and Press, “The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence,” pp. 18–32.

12 Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook* (Washington, DC: U.S. Department of Defense, 2020), pp. 3–4.

them temporarily or permanently on the territory of allied countries. On the Soviet side, there was a similar practice of forward deployment on the territory of Warsaw pact allies. In addition, Moscow has also begun developing mobile intercontinental ballistic missiles (ICBMs) in the 1970s, which could not always be monitored continuously from space, so the United States had to rely on intermittent sightings. In light of the deployment of these mobile systems, and the growing significance of ballistic missile submarines, intelligence was a central component of Cold War counterforce strategies, and overhead reconnaissance emerged as a new field of competition.¹³

Arms Race Dynamics

The requirements of survivability and reliability have both played an important role in driving up arsenal numbers and ultimately triggering an arms race between the two superpowers. In the early Cold War years, the U.S. bomber force was small and vulnerable to a Soviet preemptive attack; thus, U.S. nuclear developments were primarily focused on producing enough nuclear material to build a larger arsenal that could absorb a first strike and have enough capacity left for a counterstrike. As a result, the late 1950s and early 1960s saw a massive nuclear buildup. The United States reached a peak in 1966 with 31,255 nuclear weapons,¹⁴ and the Soviet Union reached a peak in 1986 with 45,000 nuclear weapons.¹⁵

Given the initial U.S. advantages in numbers and warhead designs, by the 1960s and 1970s, it was a popular argument that the nuclear arms race was an “action-reaction” cycle that was initiated by the United States. According to this theory, U.S. advancements compelled a responsive reaction in the Soviet Union, and if the United States decided to stop the arms race, the Soviet Union would most likely follow suit.¹⁶ One of the most influential critics of this argument was Colin Gray who demolished this thesis in his 1976 book *The Soviet-American Arms Race*.¹⁷ According to Gray, there was a variety of interactive and non-interactive behaviors and motivations that led to the Cold War nuclear arms race, and it was not a simple action-reaction cycle. For example, he mentions the possibility that states may choose to engage in an arms race to increase their diplomatic weight; their defense policy might be a captive of domestic industrial, bureaucratic, and legislative interests which can drive the arms race irrespective of adversary actions; or states might decide to race for reputation and prestige. None of these factors are contingent on action-reaction cycles, and many of them have nothing to do with adversaries.¹⁸

Gray defines the arms race as a relationship in which “there should be two or more parties perceiving themselves to be in an adversary relationship, who are increasing or improving their

13 Austin Long, *Deterrence from Cold War to Long War—Lessons from Six Decades of RAND Research* (Santa Monica, CA: RAND Corporation, 2008), p. 41.

14 National Nuclear Security Administration, “Transparency in the U.S. Nuclear Weapons Stockpile” (2024). <https://www.energy.gov/nnsa/transparency-us-nuclear-weapons-stockpile>. Accessed February 9, 2025.

15 Robert S. Norris and Hans M. Kristensen, “Global nuclear weapons inventories, 1945–2010,” *Bulletin of the Atomic Scientists* 66, no. 4 (2010), pp. 77–83.

16 Keith B. Payne, “Colin S. Gray: The Innovative Realist,” *Texas National Security Review* (July 27, 2020). <https://tnsr.org/roundtable/remembering-colin-gray/>. Accessed February 9, 2025.

17 Colin S. Gray, *The Soviet-American Arms Race* (London: Saxon House, 1976).

18 Colin S. Gray, “The Urge to Compete: Rationales for Arms Racing,” *World Politics* 26, no. 2 (January 1974), pp. 207–233.

armaments at a rapid rate and structuring their respective military postures with a general attention to the past, current, and anticipated military and political behavior of the other parties.”¹⁹ In his view, technological innovation is an important factor in any arms race, but it is not the only one. While all arms races had a quantitative and qualitative dimension, the general status of great power relations was just as important, and even if technological innovation halted for any reason, political rivalry might still feed arms race dynamics.²⁰ Two key implications arise from this argument: first, technology competition does not automatically entail an arms race; second, an arms race can exist without technology competition.

Arms races are often seen in a negative context,²¹ based on the argument that they increase the likelihood of war by introducing dangerous instabilities and exhausting resources that could be better spent. At the same time, there is a growing body of literature that suggests that arms races can also result in positive outcomes. Some scholars contend that an arms race is sometimes necessary to avoid wars and increase global stability.²²

Arms races can also stir technological innovation away from dangerous areas—as Gray argues, “arms race may lead the competitors into more stable regions of military technology.”²³ For example, the competition to increase the diversity and survivability of nuclear delivery platforms led to the development of mobile ICBMs and submarine-launched ballistic missiles (SLBMs) which might have expanded the scope of the arms race, but also made nuclear weapons more survivable against an enemy attack which disincentivized surprise attacks and increased first-strike stability.

On the warhead side, Cold War arms race dynamics required a nuclear weapons complex that was able to rapidly develop new warhead designs and produce them in large quantities. Thus, both the United States and the Soviet Union had hot production lines. In the U.S. case, the 1946 Atomic Energy Act established the Atomic Energy Commission (AEC), an independent civilian agency that oversaw nuclear energy developments and the nuclear weapons program (which included physical custody of the weapons). In the 1940s, the nuclear weapons complex included three primary “government-owned, contractor-operated” (GOCO) facilities and hundreds of smaller “contractor-owned, contractor-operated” (COCO) facilities. During the 1950s, AEC consolidated this complex into

19 Colin S. Gray, “The Arms Race Phenomenon,” *World Politics* 24, no. 1 (October 1971), p. 40.

20 Colin S. Gray, “How Does the Nuclear Arms Race Work?” *Cooperation and Conflict* 9, no. 4 (1974), pp. 285–295.

21 See, for example, Robert Jervis, *Perception and Misperception in International Politics* (Princeton, NJ: Princeton University Press, 1976); John A. Vasquez, “The Probability of War, 1816–1992. Presidential Address to the International Studies Association, March 25, 2002, New Orleans,” *International Studies Quarterly* 48, no. 1 (2004), pp. 1–28; Benjamin O. Fordham and Thomas C. Walker, “Kantian Liberalism, Regime Type, and Military Resource Allocation: Do Democracies Spend Less?” *International Studies Quarterly* 49, no. 1 (2005), pp. 141–57; Michael D. Wallace, “Arms Races and Escalation: Some New Evidence,” *Journal of Conflict Resolution* 23, no. 1 (March 1979), pp. 3–16; Michael D. Wallace, “Armaments and Escalation: Two Competing Hypotheses,” *International Studies Quarterly* 26, no. 1 (March 1982), pp. 37–56; and Susan G. Sample, “Arms Races and Dispute Escalation: Resolving the Debate,” *Journal of Peace Research* 34, no. 1 (February 1997), pp. 7–22.

22 See, for example, Samuel P. Huntington, “Arms Races: Prerequisites and Results,” *Public Policy* 8 (1958), pp. 41–86; Charles L. Glaser, “When Are Arms Races Dangerous? Rational versus Suboptimal Arming,” *International Security* 28, no. 4 (Spring 2004), pp. 44–84; Paul F. Diehl, “Arms Races to War: Testing Some Empirical Linkages,” *Sociological Quarterly* 26, no. 3 (1985), pp. 331–349; Matthew Costlow, Robert Peters, and Kyle Balzer, “A Misleading Metaphor: The Nuclear Arms Race,” *War on the Rocks* (November 20, 2023), <https://warontherocks.com/2023/11/a-misleading-metaphor-the-nuclear-arms-race/> (accessed February 9, 2025); and Gray, “The Urge to Compete: Rationales for Arms Racing.”

23 Gray, “The Urge to Compete: Rationales for Arms Racing.”

a smaller number of larger GOCO facilities constructed throughout the United States. The aim of this consolidation was to meet the needs of the Cold War nuclear buildup and produce nuclear weapons at scale.²⁴

Throughout the Cold War, the stockpile was in constant flux, due to warheads being produced, retired, or modified every day. The production capacity was at a peak in the late 1950s and early 1960s with more than 20 facilities and a production rate of 5,000-6,000 warheads a year. Nuclear materials production peaked in the early 1960s at some 60 metric tons of highly enriched uranium and 7.5 tons of plutonium per year.²⁵ Over the decades, production capacity greatly fluctuated—in the late 1970s, there were years when only a few hundred nuclear warheads were built in a year, while during the Reagan buildup, the United States regained the capacity to build 3,500-4,000 nuclear warheads a year.²⁶

The Cold War nuclear arsenal was also incredibly diverse. All warheads were developed at one of the two nuclear design laboratories, Los Alamos National Laboratory (LANL) or Lawrence Livermore National Laboratory (LLNL), supported by Sandia National Laboratories (SNL) to weaponize the warheads. Between 1946-2009, Los Alamos designed 77 types of warheads and Livermore designed 23. All four military services had nuclear weapons: the Air Force adopted 52 warhead types, the Navy 35 types, the Army 26, and the Marines 15.²⁷

There were many external factors that motivated these arms race dynamics, but there were also important domestic reasons, such as the belief that the United States could “attain security through technical superiority in nuclear weaponry.”²⁸

A key aspect of nuclear weapons production was nuclear testing. Although the scientists at the national laboratories did significant work in understanding the underlying physics of nuclear operation, their primary focus was weapons development and deployment.²⁹ During the Cold War period, the United States adopted the so-called “cut-and-try” methodology that relied on testing for several purposes.

In this approach, a device was designed and built using the best expertise of designers and engineers. Then it was tried in a nuclear test to determine if and how it would perform. Weapons must work under varied deployment conditions and over an extended lifetime. During that lifetime, radioactive materials, such as

24 Amy F. Woolf and James D. Werner, “The U.S. Nuclear Weapons Complex: Overview of Department of Energy Sites,” Congressional Research Service, R45306 (March 31, 2021). <https://crsreports.congress.gov/product/pdf/R/R45306>. Accessed February 9, 2025.

25 Thomas B. Cochran, William M. Arkin and Robert S. Norris, “U.S. Nuclear Weapons Production: An Overview,” *Bulletin of the Atomic Scientists* 44, no. 1 (1988), p. 16.

26 *Ibid.*, p. 15.

27 This data covers the period from 1946 to 2009. Robert S. Norris, “The History of the U.S. Nuclear Stockpile 1945-2013,” *Public Interest Report* 66, no. 3 (Spring 2013).

28 *Ibid.*

29 Bruce T. Goodwin, *Nuclear Weapons Technology 101 for Policy Wonks*, Center for Global Security Research Occasional Papers (Livermore, CA: Lawrence Livermore National Laboratory, August 2021), p. 39. https://cgshr.llnl.gov/sites/cgshr/files/2024-08/cgshr_nw101_policy_wonks_11-04-21_web_v5.pdf. Accessed February 9, 2025.

tritium, decay. Hence, multiple tests under these various conditions were required for each weapon type.³⁰

Nuclear testing played an important role in the design, development, certification, and deployment of nuclear weapons. Nuclear tests helped to prove that a weapon would work as intended, and they also helped to advance nuclear weapon design, determine weapons effects and verify weapon safety.³¹

Between July 1945 and September 1992, the United States conducted 1,054 nuclear tests.³² While these tests were important in the certification of new weapon designs,

nuclear weapons were never certified by nuclear tests; nuclear tests were important, but frequently not even the most important part of the process because there were never enough nuclear tests over the full range of conditions to provide certification based on the empirical data from those tests. Certification was a statement of confidence and the judgment of technical experts based on a rigorous process that considered all the available data, computational simulations, considerations of margins, etc.³³

Given the rapid pace of the Cold War arms race, it was also important that the whole cycle of warhead design, development, certification, and deployment happened at the speed of relevance. The establishment of the AEC and the consolidation of the weapons complex played an important role in improving efficiency and enabling shorter timelines for these processes. As a result, the first modern, miniature hydrogen bomb (the W-47) went from design to deployment in less than three years between 1957 and 1960.³⁴

Altogether, in the Cold War period, arms race dynamics evolved hand-in-hand with intense technology competition. The increasing demands of the arms race required continuous innovation and great diversity in nuclear warhead designs, a fast-paced production capacity that produced nuclear weapons at scale, and a highly efficient process that was able to bring new concepts from design to deployment in a relatively short timeframe.

30 Anna Péczeli and Bruce T. Goodwin, *Technical Issues in the Comprehensive Nuclear Test Ban Treaty (CTBT) Ratification Debate: A 20 Year Retrospective*, Center for Global Security Research Occasional Papers (Livermore, CA: Lawrence Livermore National Laboratory, September 2020), p. 11. https://cgsr.llnl.gov/sites/cgsr/files/2024-08/cgsrctbtonline_0.pdf. Accessed February 9, 2025.

31 United States Department of Energy, "United States Nuclear Tests—July 1945 through September 1992," National Nuclear Security Administration Nevada Field Office, DOE/NV-209-REV 16 (September 2015), p. vii. https://nns.gov/wp-content/uploads/2023/08/DOE_NV-209_Rev16.pdf. Accessed February 9, 2025.

32 Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook*, p. 184.

33 George Miller quoted in Paul Brown, *The Comprehensive Test Ban Treaty: Lawrence Livermore National Laboratory's Impact on U.S. Nuclear Policy from 1958 to 2000* (Livermore, CA: Lawrence Livermore National Laboratory, 2019), p. 142.

34 Lawrence Livermore National Laboratory, "A Strategic Breakthrough—1956 Polaris," LLNL Through the Decades (undated). <https://www.llnl.gov/sites/www/files/1956.pdf>. Accessed February 9, 2025.

Technology Competition

The development of new technologies can provide countries with opportunities to gain significant military advantage. In the nuclear domain, advances in materials science, electronics, and propulsion systems have been used to create more efficient, reliable, and survivable nuclear weapons. These technological advancements have played a very important role in the Cold War period. Innovation was required not only to fulfill the deterrence requirements of survivability and reliability, but also to meet the growing demands of the arms race, like developing the ability to put multiple warheads on a single missile. While the early 1950s were rather characterized by quantitative advancements in the U.S. nuclear arsenal, from the 1960s on, technological innovation facilitated dramatic qualitative improvements in nuclear forces.

There are many competing theories about the role of technology and innovation.³⁵ According to the optimistic—or rationalistic—explanation, technological advancements are driven by political and military leaders who assess the security environment and identify which existing technologies are required to solve specific problems and what new technologies need to be developed. In this approach, technological innovation is the dependent variable that is driven by national security needs. The alternative approach is technological determinism that reverses the logic of the rationalistic approach and argues that “when technology beckons, men are helpless [...] If a thing was technically possible, then it had to be done. Such was the terrible thrust of technology in the nuclear-missile era. Technology, itself, was proving to be the great enemy of arms control.”³⁶ Those who see technology as deterministic generally blame technological innovation for the Cold War arms race and advocate measures that would reassert the primacy of politics over technology.

The reality, however, is more nuanced, and both approaches have elements of truth. One of the best models that captures this duality is Matthew Evangelista’s model of innovation.³⁷ He distinguishes between different phases of weapons development and argues that technological and political, and external and internal factors weigh differently in each of these phases. In the case of the United States, its individualistic culture, free market, entrepreneurial economy, and democratic political system promote a highly innovative culture, where new ideas usually come from the bottom, and each stage of weapons development entails building a larger constituency, until the idea receives top-level support. Because of these bottom-up dynamics, domestic factors play a highly influential role in the development of new weapons systems.

In contrast, the Soviet culture was rigid, and decisions were always made at the top which stood in the way of innovation. Initiatives by the bottom levels were subject to meeting predetermined requirements by the top level that was usually responsive to the changes of the international system or major developments by the United States. Thus, in this case, external factors are more important in the development of new weapons.

35 See more about this in Donald MacKenzie, “Technology and the Arms Race—Review: Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies by Matthew Evangelista,” *International Security* 14, no. 1 (Summer 1989), pp. 161–175.

36 Ralph Lapp, *Arms Beyond Doubt: The Tyranny of Weapons Technology* (New York, NY: Cowles, 1970), p. 178.

37 Matthew Evangelista, *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies* (Ithaca, NY: Cornell University Press, 1988).

With regard to the Cold War nuclear arms race, many organizational factors also played an important role in empowering U.S. scientists and reinforcing the bottom-up dynamics. The close personal ties between scientists and military officers enabled by the Manhattan Project, overlapping memberships between different jurisdictions and laboratories, and loose lines of authority between regulatory and advisory panels have allowed Cold War scientists to play a highly influential role in U.S. force structure decisions. The best example is the case study of tactical nuclear weapons. The development of this capability was initially proposed by a small group of scientists (such as Robert Oppenheimer) who were morally opposed to the use of strategic nuclear weapons (especially the hydrogen bomb) on Soviet cities and saw tactical nuclear weapons as a morally more acceptable alternative in the late 1940s.

This phased approach basically validates all previous assumptions with some caveats. In the early stages of weapons development, Evangelista emphasizes the role of innovation driven by scientists' desire to advance technologies, but instead of assuming a deterministic view of technology, he acknowledges that scientists themselves are often driven by external factors and policy objectives as they shape innovation. He also emphasizes that in the later stages of weapons development, high-level buy-in and political consensus is needed, which is often contingent on external factors, such as the Soviet threat.

The Cold War has seen many important advancements in nuclear weapons technology. Early efforts in nuclear warhead development were focused on increasing the yield of nuclear weapons to counterbalance inaccuracies in delivery platforms and meet the requirement of reliability. In this regard, the evolution of weapons designs led to three distinct categories. The first nuclear weapons were *pure fission weapons* (like the ones that were used in Hiroshima and Nagasaki) that used a supercritical mass of fissile material (plutonium and/or uranium), and neutrons were injected into the supercritical assembly to start a fission chain reaction. The second type of nuclear weapon is *boosted fission weapons* where a fission explosion causes a small fusion reaction that reacts back onto the fissioning material with fusion neutrons to "boost" the fission explosion yield. The third type of nuclear weapon is *thermonuclear weapons* where X-ray energy from a primary fission stage implodes a separate (secondary) thermonuclear (fusion) stage.³⁸ Among the three categories, fusion weapons are the most technically complex designs that can produce a much larger yield than the other designs.³⁹ Over time, all five nuclear weapon states (the United States, the United Kingdom, France, China, and Russia) recognized by the Nuclear Non-Proliferation Treaty (NPT) have developed modern thermonuclear weapons, which typically use a boosted fission first stage to drive a thermonuclear second stage.

Since early nuclear designs were enormous and heavy, there were serious limitations on what delivery platforms can carry these weapons. Thus, the next big technical challenge was improving the yield-to-weight ratios of nuclear weapons designs. Miniaturization helped to make nuclear weapons smaller and lighter which allowed states to deploy them on various platforms such as missiles and smaller aircraft. In the United States, the first miniature atomic bomb was invented by John Foster at

38 Goodwin, *Nuclear Weapons Technology 101 for Policy Wonks*, pp. 16–23.

39 Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook*, p. 165.

LLNL—the new design was successfully demonstrated in the nuclear test code named Tesla in 1955.⁴⁰ This was a key milestone in developing modern, miniature hydrogen bombs. The Navy was specifically interested in miniature nuclear weapons because miniaturization made it possible to deploy nuclear weapons on SLBMs. Since scientists at LLNL have already been working on miniaturizing the thermonuclear secondary, LLNL received the contract to develop a new warhead for the Navy. In only five years, LLNL scientists managed to achieve a 15-fold yield-to-weight improvement in warhead design, which allowed the Navy to deploy the new W-47 warhead (the first modern, miniature thermonuclear weapon) on the Polaris missiles in October 1960.

Following the announcement of the Polaris deployment, the Soviet Union launched an intense nuclear testing campaign to close the technological gap with the United States. Despite the Soviet advantages in missile throw-weight, this invention gave the United States a serious technological edge. While Soviet warheads were huge and heavy, U.S. warheads were miniaturized, which meant that U.S. missiles did not need to have the same throw-weight to be competitive. Up until 1960, the Soviet Union believed that it had a technological parity with the United States since it had also successfully tested a fission device, and it was the first to deploy a thermonuclear weapon in 1953. But the deployment of the Polaris missiles clearly demonstrated a major gap between U.S. and Soviet technological advancements. Deploying miniature nuclear weapons on SLBMs gave the United States a secure second-strike capability, while Soviet bombers and missiles were still vulnerable to U.S. attacks.

This technological milestone also paved the way for the invention of the first MIRVed warhead in 1964. Following another four-fold reduction in size, strategic re-entry vehicles reached their zenith of miniaturization, allowing the United States to deploy MIRVed warheads on its Poseidon SLBMs and Minuteman ICBMs starting in 1970.⁴¹ This development significantly increased the credibility of U.S. nuclear deterrent in the face of Soviet technological advancements in antiballistic missile defenses.

Throughout the Cold War, competition between the two superpowers drove innovation and pushed the boundaries of military technology. In the U.S. case, bureaucratic-organizational factors created an environment that was conducive to innovation and allowed scientists to play a key role in shaping the Cold War technology competition. As former LLNL director Herbert York pointed out, in the 1950s and 1960s “the technology actually preceded the doctrine in most cases, if not in all cases.”⁴² By the 1960s and early 1970s, groundbreaking innovations coming from the national laboratories gave the United States a significant technological edge over the Soviet Union. These advancements improved the credibility of U.S. nuclear deterrent and provided U.S. leaders with bargaining advantages in crisis situations like the Berlin Crisis in 1961 and the Cuban missile crisis in 1962.

Altogether, in the Cold War years, technology competition was a key aspect of arms racing, and the two mutually reinforced each other. The symbiotic relationship between arms race dynamics and innovation was most notable in advancements in warhead designs and delivery platforms. At the same time, not all aspects of innovation at the nuclear weapons laboratories were focused on outmatching the Soviet Union. LLNL, for example, played a pivotal role in advancing atmospheric sciences and bioscience, including developing a capability to make genome sequencing possible.

40 Goodwin, *Nuclear Weapons Technology 101 for Policy Wonks*, p. 27.

41 *Ibid.*, pp. 25–31.

42 Quoted in Gray, “The Urge to Compete: Rationales for Arms Racing,” p. 228.

In the meanwhile, LANL made important advancements in satellite sensors that facilitated nonproliferation activities through the monitoring of clandestine nuclear tests. Thus, technology competition went way beyond the scope of the arms race, and some of these advancements provided benefits on a global scale.

Technology Competition and Arms Racing in the Current Security Environment

In the post-Cold War environment, the collapse of the Soviet Union and the general optimism about the possibility to build a more cooperative relationship with Russia brought dramatic reductions in the number and role of nuclear weapons. Nuclear competition was replaced by cooperation, arms control, and risk reduction.⁴³ As a result of the 1991-1992 Presidential Nuclear Initiatives (PNI)⁴⁴ and the 1991 Strategic Arms Reduction Treaty (START I),⁴⁵ U.S. nuclear forces were reduced from 21,000 nuclear weapons in 1990 to about 10,000 in 2000. Considering the overall reductions with the Russians, by the time START I was fully implemented in 2001, 80% of the world's strategic nuclear weapons were dismantled.⁴⁶ As a result of the PNIs, the United States eliminated its worldwide inventory of non-strategic nuclear weapons and only preserved a small arsenal of air deliverable weapons in Europe. These measures have not only reduced the number of nuclear weapons, but also reduced their diversity.

Parallel with these reductions, the United States has also reduced its reliance on nuclear weapons and refocused its efforts on developing new non-nuclear capabilities that were better suited for the new strategic environment, where the primary concern was weapons of mass destruction (WMD) threats from rogue states. Due to these developments, the United States ended nuclear weapons production in 1991 and halted nuclear testing in 1992. Instead of building new capabilities, the primary challenge was sustaining the legacy deterrent. The National Defense Authorization Act (NDAA) for Fiscal Year 1994 directed the Department of Energy (DOE) to establish a Stockpile Stewardship Program (SSP) to guarantee that the stockpile remained safe, secure, and effective without the need to conduct nuclear explosive tests.⁴⁷

Despite the rather benign security landscape, technology competition did not simply go dormant in this era. Nuclear technologies had to continuously evolve and adapt to the new requirements. In this regard, two key areas stand out: stockpile stewardship and arms control verification. Maintaining the legacy stockpile without nuclear testing posed an immense technical challenge that required major advancements in science and technology. Similarly, broader arms control objectives had important implications for technology development in verification and monitoring tools. Defending

43 See more about this in Roberts, "The Next Chapter in U.S. Nuclear Policy."

44 Susan J. Koch, "The Presidential Nuclear Initiatives of 1991-1992," National Defense University, Center for the Study of Weapons of Mass Destruction (2012). https://ndupress.ndu.edu/portals/68/documents/casestudies/cswmd_casestudy-5.pdf. Accessed February 9, 2025.

45 "Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of the Strategic Offensive Arms and Associated Documents," U.S. Department of State—Archived Content (1991). <https://2009-2017.state.gov/t/avc/trty/146007.htm>. Accessed February 9, 2025.

46 "Strategic Arms Reduction Treaty (START I)," Center for Arms Control and Non-Proliferation (November 16, 2022). <https://armscontrolcenter.org/strategic-arms-reduction-treaty-start-i/>. Accessed February 9, 2025.

47 Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook*, p. 4.

against WMD threats, developing the needed monitoring tools to curtail illicit trafficking, and verifying agreements such as the Comprehensive Nuclear Test-Ban Treaty (CTBT) were all contingent on certain technological advancements. Thus, while the arms race ended with the Cold War, technology competition endured. Although it changed in intensity, nature, and scope, it never really went away.

Russia's annexation of Crimea in 2014 opened a new chapter in nuclear competition. Despite the optimism about the peace dividend, and the general expectation that geopolitical competition will be replaced with cooperation, great power relations have dramatically deteriorated, and new competitive dynamics have emerged. The following sections will explore the main features of this renewed competition and show how the current context is different from the Cold War experience.

Deterrence Requirements and the Main Areas of Competition Today

In the current security environment, the United States had to slowly shift its focus back to major power rivalry and figure out how to respond to the new deterrence problems that its adversaries have created. Although the United States did not choose this competition for itself, it cannot ignore these dramatic changes in the strategic landscape if it wants to maintain the credibility of its nuclear deterrent. According to Brad Roberts,⁴⁸ three key developments stand out with nuclear policy implications: 1) major power relations have turned for the worse; 2) the failure of the effort to prevent nuclear proliferation by North Korea; and 3) the crumbling of the arms control architecture.

Regarding the first, both Russia and China have emerged with revisionist ambitions and pose serious challenges to the U.S.-backed regional security order. They have both developed strategies to defeat a conventionally superior nuclear-armed rival with an extensive alliance system. These strategies rest on the belief that in a regional confrontation, there would be an asymmetry of stakes that adversaries can exploit with limited acts of escalation (including nuclear attacks) to coerce the United States into surrender. Thus, nuclear blackmail and brinkmanship are an important element of adversary postures. Additionally, adversary leaders believe that they can use information confrontation strategies to break the resolve of the United States and its allies.

The second development means that U.S. nuclear deterrence must also account for nuclear-armed regional challengers (such as North Korea, and most likely Iran as well). Lastly, the crumbling of the arms control architecture means that adversary nuclear forces are mostly unconstrained in this environment (one of the last mechanisms, the New START agreement will expire in 2026), and cooperative monitoring of nuclear forces is probably coming to an end.

In addition to the challenges of growing multipolarity, there is a proliferation in escalatory pathways⁴⁹ due to intensifying competition in non-nuclear strategic capabilities, and the great powers' increased reliance on multi-domain warfare.

In terms of deterrence requirements, this multipolar and multi-domain environment means that survivability and reliability are more important than ever. At the same time, U.S. nuclear forces also need to be tailored to a number of new adversaries and new circumstances.

48 Roberts, "The Next Chapter in U.S. Nuclear Policy."

49 James N. Miller Jr. and Richard Fontaine, "A New Era in U.S.-Russian Strategic Stability: How Changing Geopolitics and Emerging Technologies are Reshaping Pathways to Crisis and Conflict," Center for a New American Security (September 2017). <https://s3.amazonaws.com/files.cnas.org/documents/CNASReport-ProjectPathways-Finalb.pdf?mtime=20170918101504>. Accessed February 9, 2025.

As mentioned earlier, survivability has traditionally meant seeking the strategies of hardening, concealment, and redundancy. As nuclear delivery platforms have become more accurate by the mid-1980s, hardened targets became more vulnerable. These trends have further accelerated in the post-Cold War years with a new wave of technological advancements in navigation and guidance. While an SLBM only had a 9% chance of destroying a hardened missile silo in 1985, this number was 80% by 2017. Improvements in navigation and guidance have also led to major developments in laser- and GPS⁵⁰-guided smart weapons (bombs and cruise missiles) that can adjust their trajectory as they fly and guide themselves to the determined targets. These leaps in accuracy have also resolved other technical problems such as fratricide which has further reduced the likelihood that modern missiles would miss their targets.⁵¹

In addition to the increased accuracy of missiles, the reentry vehicles of most U.S. SLBMs are now equipped with new compensating super-fuses that provide an ability to compensate for inaccuracies between the actual and expected trajectory of a reentry vehicle by adjusting the warhead's height of burst.⁵² This development has significantly increased the effectiveness of modern SLBMs against hardened targets, and it could make first-strike options more tempting.

Lastly, ICBM and SLBM effectiveness has also benefited from rapid missile retargeting which, in case of a malfunctioning missile, allows launch control centers to reassign targets to other missiles in reserve. This capability has been installed for both ICBM and SLBM launch centers after the Cold War.⁵³ The cumulative effect of these technological developments is that the reliability of nuclear attacks has significantly increased while survivability based on hardening is essentially undermined.

The strategy of concealment faces similarly tough challenges. Technological advancements in remote sensing are making it more difficult than ever for mobile platforms to hide. Sensor platforms have become more diverse, and they are collecting a widening array of signals. Unlike in the Cold War, they provide persistent observation, sensor resolution has improved, and there is a huge increase in data transmission speed. While the United States continues to enjoy advantages in these areas over its adversaries, maintaining the survivability of submarines and mobile missiles has become harder for all sides.⁵⁴ As a result, there is an increasing technology competition in the development of countermeasures, such as radar jammers, anti-satellite weapons, and decoys. From a U.S. perspective, the good news is that those who enjoy advantages in sensing technologies are generally better at developing countermeasures.⁵⁵ At the same time, this is a daunting challenge, since states must respond to a large array of new technologies, and certain vulnerabilities are very difficult to fix.

50 Global Positioning System

51 Lieber and Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," pp. 20–22.

52 Hans M. Kristensen, Matthew McKinzie, and Theodore A. Postol, "How US nuclear force modernization is undermining strategic stability: The burst-height compensating super-fuze," *Bulletin of the Atomic Scientists* (March 1, 2017). <https://thebulletin.org/2017/03/how-us-nuclear-force-modernization-is-undermining-strategic-stability-the-burst-height-compensating-super-fuze/>. Accessed February 9, 2025.

53 Lieber and Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," pp. 24–27.

54 *Ibid.*, pp. 32–34.

55 Brendan Rittenhouse Green and Austin Long, "Conceal or Reveal? Managing Clandestine Military Capabilities in Peacetime Competition," *International Security* 44, no. 3 (2020), pp. 48–83.

In terms of redundancy, growing multipolarity poses a difficult problem. For the first time in its history, the United States is faced with two major nuclear challengers, while it also must address rogue threats from North Korea (and probably Iran in the future). Due to the growing collaboration between these states, there is a possibility of simultaneous attacks, either as a coordinated effort, or as an opportunistic aggression in the second theater.⁵⁶ This simultaneity increases the burden for redundancy, which also means that the United States can no longer posture its nuclear forces simply based on Russian force levels and consider others as “lesser included cases.”

With regard to the reliability of nuclear forces, many of the above-mentioned developments have increased the likelihood that a nuclear attack would reach its target and destroy it. At the same time, a huge challenge in the current security environment is that nuclear command, control, and communications (NC3) systems are facing many vulnerability problems that carry nuclear escalatory risks. First, technological advancements make it easier to locate and attack NC3 systems. Second, there is growing entanglement between conventional and nuclear command and control (C2) systems which makes it more likely that these systems would be attacked in the early stages of a conventional confrontation (and, as a consequence, trigger a nuclear response). Third, many nuclear powers (especially Pakistan, North Korea, Russia, and China) have increased their reliance on nuclear weapons to counterbalance the conventional advantages of their adversaries, which means that even modest degradation of their NC3 systems could trigger an escalatory response.⁵⁷ The main implication of these vulnerability problems is that they increase first-strike and crisis instabilities. Unfortunately, the solution is not exactly straightforward since many of the Cold War remedies would only trade one type of danger for another. For example, adopting higher alert levels, dispersing nuclear weapons, and decentralizing launch authority could lower some of these threats against NC3 systems, but they would also increase other types of concerns, such as risks associated with accidental or unauthorized nuclear use. An additional problem is that many of these dangers are generally underappreciated or not even recognized by nuclear possessors.⁵⁸

In addition to survivability and reliability, U.S. nuclear forces also need to be tailored. The underlying logic of the U.S. nuclear deterrent is to hold at risk what the enemy values the most. Given

56 Madelyn R. Creedon, Jon L. Kyl et al., “America’s Strategic Posture—The Final Report of the Congressional Commission on the Strategic Posture of the United States,” Institute for Defense Analyses (October 2023). <https://www.ida.org/research-and-publications/publications/all/a/am/americas-strategic-posture>. Accessed February 9, 2025.

57 Daryl G. Press, “NC3 and Crisis Instability—Growing Dangers in the 21st Century,” Nautilus Institute for Security and Sustainability, NAPSNet Special Reports (October 17, 2019). <https://nautilus.org/napsnet/napsnet-special-reports/nc3-and-crisis-instability-growing-dangers-in-the-21st-century/>. Accessed February 9, 2025.

58 Tong Zhao, *Political Drivers of China’s Changing Nuclear Policy: Implications for U.S.-China Nuclear Relations and International Security* (Washington, DC: Carnegie Endowment for International Peace, 2024), p. 53, <https://carnegieendowment.org/research/2024/07/china-nuclear-buildup-political-drivers-united-states-relationship-international-security?lang=en> (accessed February 9, 2025); Fiona S. Cunningham and Taylor M. Fravel, “Dangerous Confidence? Chinese Views on Nuclear Escalation,” *International Security* 44, no. 2 (2019), pp. 61–109; Anya Fink and Michael Kofman, “Russian Strategy for Escalation Management: Key Debates and Players in Military Thought,” Center for Naval Analyses (2020), https://www.cna.org/cna_files/pdf/DIM-2020-U-026101-Final.pdf (accessed February 9, 2025); and Michael Kofman, Anya Fink, and Jeffrey Edmonds, “Russian Strategy for Escalation Management: Evolution of Key Concepts,” Center for Naval Analyses (2020), https://www.cna.org/CNA_files/PDF/DRM-2019-U-022455-1Rev.pdf (accessed February 9, 2025).

the increased number of adversaries, and the growing number of contingencies, the ability to tailor nuclear deterrence puts new burdens on U.S. nuclear forces.⁵⁹

First, this entails flexible response options—this

ensures that the president has a sufficient range of response options following adversary escalation to terminate a conflict on terms acceptable to the United States and its Allies and partners at the lowest level of damage possible. Flexible response options are required to deter adversary limited nuclear escalation when a large-scale U.S. nuclear response might not be credible.⁶⁰

In order to increase flexibility, delivery platforms must provide a diversity of ranges and trajectories, and a diversity of deployment modes (including the option of forward deployment). The next implication of tailoring is that U.S. nuclear forces need to be responsive—the capacity to deploy and employ forces as promptly as is necessary to pose credible threats.⁶¹

Currently, U.S. delivery systems include the Minuteman III ICBMs, the Trident II D5 SLBMs, the F-15 and F-16 certified NATO legacy aircraft, the F-35 certified NATO aircraft, and the B-2 and B-52 bombers. This is not only a significant reduction in diversity in comparison to Cold War levels, but also a much smaller variety in comparison to current adversary delivery platforms. Russia, for example, deploys seven types of ICBMs, two types of SLBMs, an intercontinental-range nuclear-armed torpedo, and two types of bombers.⁶² In non-strategic nuclear weapons (NSNW), the U.S. State Department estimates that Russia has a

stockpile of roughly 1,000 to 2,000 NSNW warheads [which] includes warheads for air-to-surface missiles, gravity bombs, depth charges, torpedoes, anti-aircraft, anti-ship, anti-submarine, anti-ballistic missile systems, and nuclear mines, as well as nuclear warheads for Russia’s dual-capable ground-launched SS-26 Iskander missile systems.⁶³

While the United States does not need to match adversary nuclear forces one-for-one to have a credible nuclear deterrent, it must balance the much smaller diversity in nuclear forces against an increasing number of tasks. These tasks include addressing the growing number of targets due

59 Roberts, “The Next Chapter in U.S. Nuclear Policy.”

60 Creedon, Kyl et al., “America’s Strategic Posture—The Final Report of the Congressional Commission on the Strategic Posture of the United States,” p. 26.

61 Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook*, p. 7.

62 Jacek Durkalec, *Russian Net Assessment and the European Security Balance*, Livermore Paper No. 14 (Livermore, CA: Lawrence Livermore National Laboratory, 2022), pp. 123–126. https://cgsr.llnl.gov/sites/cgsr/files/pubs/2024-08/CGSR_Livermore_Paper_13_Russian-Net-Assessment.pdf. Accessed February 9, 2025.

63 U.S. Department of State, “Report to the Senate on the Status of Tactical (Nonstrategic) Nuclear Weapons Negotiations Pursuant to Subparagraph (A)(12)(b) of the Senate Resolution of Advice and Consent to Ratification of the New START Treaty” (May 2023). <https://www.state.gov/wp-content/uploads/2023/05/NSNW-2023-Unclass-Report-02-09-23-1-w-no-class-markings-Accessible-2.14.2023.pdf>. Accessed February 9, 2025.

to adversary modernization efforts, maintaining effective nuclear response options to deter and counter adversary limited nuclear use scenarios in theater, addressing assurance and extended deterrence needs to deploy forces in remote theaters, compensating for any shortfalls in U.S. and allied non-nuclear capabilities if the United States is confronted with a sequential or simultaneous two-theater war, and addressing advancements in adversary integrated air- and missile defense systems.⁶⁴ Additionally, the United States must also hedge against unforeseen technical problems in its existing arsenal and prepare for sudden changes in the geopolitical environment. Given all these requirements, U.S. competitiveness might require greater numbers in deployed forces, and potential adjustments in the diversity of delivery platforms as well.

Arms Race Dynamics

Over the past decade, Russia, China, and North Korea have all accelerated their nuclear modernization programs and increased the number and diversity of their nuclear weapons stockpile. These trends are most striking in the Chinese case. Estimates suggest that China's operational nuclear warhead stockpile was slightly over 400 warheads in 2021, and that it will field over 700 nuclear warheads by 2027, over 1,000 warheads by 2030, and could reach 1,500 deployed warheads by 2035. China is also building a larger and more capable missile and bomber force that is more survivable, more diverse, and on higher alert. These developments are aimed at providing a better ability to manage regional escalation scenarios and strengthening its intercontinental second-strike capability. To support the expansion of its nuclear program, China will probably use its new fast breeder reactors and reprocessing facilities to produce the necessary plutonium.⁶⁵

Russia currently has the largest and most diverse nuclear arsenal in the world, and it continues to expand and modernize these capabilities. By 2022, the share of advanced strategic missile systems in Russia's stockpile has risen to 91%.⁶⁶ Russia has also upgraded its sea-based strategic deterrent by deploying the more reliable and quieter Borey class SSBNs and it has also developed a number of new warhead designs for its strategic systems. Russia also introduced an array of "novel" strategic capabilities: the Avangard hypersonic glide vehicle (HGV), the Sarmat heavy ICBM, a nuclear-armed, nuclear-powered underwater vehicle (Poseidon), and a nuclear-powered, nuclear-armed intercontinental-range cruise missile (Burevestnik). The buildup of strategic forces was supported by the availability of large stockpiles of plutonium and highly enriched uranium, and a nuclear weapons infrastructure and production complex that is able to produce thousands of nuclear warheads each year and, if needed, expand this capacity. Due to these hot production lines, Russia's nuclear weapons have an average age of approximately five years.⁶⁷

64 Kyl Creedon et al., "America's Strategic Posture—The Final Report of the Congressional Commission on the Strategic Posture of the United States," p. viii.

65 U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China, the People's Liberation Army (PLA)*, Annual Report to Congress (October 19, 2023), <https://media.defense.gov/2023/Oct/19/2003323409/-1/-1/1/2023-MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA.PDF> (accessed February 9, 2025); Kyl Creedon et al., *America's Strategic Posture—The Final Report of the Congressional Commission on the Strategic Posture of the United States*, pp. 12–13.

66 President of Russia, "Meeting of Defence Ministry Board" (December 21, 2022). <http://en.kremlin.ru/events/president/transcripts/70159>. Accessed February 9, 2025.

67 Durkalec, *Russian Net Assessment and the European Security Balance*, pp. 120–128.

Because of these trends, numerous reports talk about a new arms race.⁶⁸ However, as Gray has noted, an arms race requires two or more parties that are in an adversarial relationship to improve their armament at a rapid pace. While these conditions were present in the Cold War, they are missing today (and they are not likely to emerge anytime soon). First, the United States has not matched the nuclear developments of its adversaries, and second, even if adjustments are going to happen, they will be modest and restrained due to infrastructure constraints, which is less likely to trigger an action-reaction spiral.

In the post-Cold War environment, the United States has opted to stop nuclear weapons production and pursue a science-based Stockpile Stewardship Program that builds on science methods and advanced computing to guarantee that the stockpile remains safe, secure, and effective without nuclear testing. Due to the development of new scientific, computational, and technical tools and methodologies, this program has been able to certify the continued viability of the U.S. nuclear stockpile for the past three decades.⁶⁹ Unlike its adversaries, the United States has not fielded newly designed warheads (with new components) since 1991. Instead it focused on “creating a warhead replacement program that would [...] move away from the highly optimized warheads of the Cold War toward designs, materials, and components with more robust performance margins, longer lifetimes, and easier fabrication and maintenance.”⁷⁰ To support this effort, the United States significantly increased the capability of the laboratory complex, conducted a major consolidation and modernization of the production complex, and developed a better approach to stockpile sustainment. Despite some skeptical voices in the 1990s, this program has proved to be a massive success, and it even helped to improve understanding of the physics, engineering, and materials science processes that affect nuclear weapons performance.⁷¹

At the same time, the choices the United States made in the early 1990s were done in a benign security environment, where the expectation was that global nuclear stockpiles will continue to go down, and adversary nuclear developments will be capped by arms control agreements. While its adversaries have embarked on a massive modernization pathway, the United States has not implemented the necessary changes to remain competitive in a two-peer environment.

Unlike its adversaries, the United States decided to execute Life Extension Programs (LEPs) to maintain a legacy Cold War stockpile that has reached the end of its original design life. Although LEPs have successfully resolved aging and performance issues, enhanced safety features, and improved

68 See, for example, “America Prepares for a New Nuclear-Arms Race,” *The Economist*; Paul Dibb, “A New US, Russia, China Nuclear Arms Race Spells Danger;” United Nations, “Nuclear Arms Race ‘Heading in Wrong Direction,’ United Nations Chief Warns, as General Assembly Marks Day for Their Total Elimination;” and Michael T. Klare, “The Nuclear Arms Race Is Back and More Terrifying Than Ever,” *The Nation* (September 17, 2024), <https://www.thenation.com/article/world/nuclear-war-new-start/> (accessed February 9, 2025).

69 George Miller, “Stockpile Stewardship: What Were We Thinking? How Did It Work Out?” in Brad Roberts, ed., *Stockpile Stewardship in an Era of Renewed Competition* (Livermore, CA: Lawrence Livermore National Laboratory, April 2022), pp. 6–19. https://cgsr.llnl.gov/sites/cgsr/files/2024-08/cgsr_occasional_stockpile-stewardship-era-renewed-competition.pdf. Accessed February 9, 2025.

70 *Ibid.*, pp. 6–7.

71 Péczeli and Goodwin, *Technical Issues in the Comprehensive Nuclear Test Ban Treaty (CTBT) Ratification Debate: A 20 Year Retrospective*.

the security of the weapons, they have been constrained by the prohibition on “new” warheads.⁷² As a result, former LLNL director George Miller argues that “NNSA [National Nuclear Security Administration] and the laboratories have missed opportunities to implement changes that create ‘new’ warheads that are more robust, easier to manufacture, or easier to sustain because of concerns that they might also have different military characteristics.”⁷³

In the current stockpile, the average duration since a warhead was manufactured or refurbished is roughly 28 years.⁷⁴ The United States has an arsenal with only seven types of warheads and bombs: the W78 and W87 ICBM warheads, the W76 and W88 SLBM warheads, the B61 and B83 bombs, and the W80 air-launched cruise missile (ALCM) warhead.⁷⁵ In comparison to the Cold War period, this number is a significant reduction in diversity. While efforts are underway to transition from legacy to modernized systems and “new” warheads like the W93 will be added to this stockpile, tailoring deterrence in the current security environment might require more diverse and graduated responses with a spectrum of yield options and weapon types. As the 2023 bipartisan Strategic Posture Commission recommended, “the current modernization program should be supplemented to ensure U.S. nuclear strategy remains effective in a two-nuclear-peer environment.”⁷⁶

Adjustments are also necessary in the nuclear weapons complex. According to the Strategic Posture Commission, “due to previous years of neglect and a dangerous threat environment, the infrastructure (facilities and workforce) that enables development and fielding of strategic capabilities needs to be overhauled.”⁷⁷ Delivering the modernization of the program of record (POR) on time is a key priority, but adding supplemental capabilities is also necessary. These demands put a huge pressure on the already constrained infrastructure, and recapitalization will be needed to build the capacity of the complex’s production capability. At the heart of this process is building facilities to manufacture plutonium pits.

Altogether, while U.S. adversaries have been racing for years, the United States has not followed their path. First, it has not shown the political will to enter a new arms race; and second, it currently does not have the capacity to do so. Therefore, speculations about a newly unfolding nuclear arms race are unfounded, and given the time and effort it would take to build the capacity to match adversary modernization efforts, this is unlikely to change in the short or medium term.

Technology Competition

In terms of major technological advancements in weapons designs, developing modern miniaturized hydrogen bombs is a key milestone. Once nuclear possessors achieve this, they can field

72 National Nuclear Security Administration, “The U.S. Nuclear Weapons Stockpile” (undated). <https://www.energy.gov/nnsa/us-nuclear-weapons-stockpile>. Accessed February 9, 2025.

73 Miller, “Stockpile Stewardship: What Were We Thinking? How Did It Work Out?” p. 14.

74 National Nuclear Security Administration, “The U.S. Nuclear Weapons Stockpile.”

75 National Nuclear Security Administration, “Fiscal Year 2025 Stockpile Stewardship and Management Plan – Biennial Plan Summary,” U.S. Department of Energy (September 2024). <https://www.energy.gov/sites/default/files/2024-10/FY2025%20Stockpile%20Stewardship%20and%20Management%20Plan.pdf>. Accessed February 9, 2025.

76 Kyl Creedon et al., *America’s Strategic Posture—The Final Report of the Congressional Commission on the Strategic Posture of the United States*, p. viii.

77 *Ibid.*, p. 51.

nuclear warheads on a wide range of delivery platforms, and they can also develop MIRVed systems. For the more advanced nuclear powers who have already reached this milestone (this includes all five permanent members of the United Nations Security Council, also known as the P5 states), the playing field evens out, but for those who have not acquired this capability yet (for example, North Korea), there are immense gains to be unlocked.

This, however, does not mean that innovation in nuclear weapons technologies have no more relevance for the great powers' modernization efforts. In warhead designs, the United States is slowly moving away from some of its old approaches. For example, the W87-1 modernization program is the first LEP in which the warhead will be entirely manufactured from scratch, and the W93 replacement for the Navy is going to be the first warhead that is designed against a new set of sustainment requirements.⁷⁸ In general, weapons technology and manufacturing efforts are aimed at developing agile, affordable, assured, and novel technologies to support nuclear sustainment and modernization programs. Research and development efforts include new materials and advanced manufacturing techniques (such as additive manufacturing) to improve weapon component production, enable new component design, and replace hazardous materials with safer alternatives. While these advancements might not be as groundbreaking as developing a two-stage weapon or miniaturizing a warhead design, they improve the overall resilience of the weapons complex by enabling a transition away from legacy systems, materials, and processes.⁷⁹

Innovation has also played an important role in compensating for the moratorium on nuclear explosive testing. NNSA is operating modern science facilities, where research and development, modeling of nuclear weapons performance, and computer simulations have proven to be viable substitutes for nuclear explosive tests for more than three decades. Nuclear fusion breakthroughs at the National Ignition Facility at LLNL are helping to advance a better understanding of the stockpile, providing knowledge that was only accessible through nuclear explosive tests in the past. Cutting-edge research on high-performance computers and modeling capabilities are helping to mitigate the effects of aging, and they are also helping to design new systems.⁸⁰ In comparison to its adversaries, the United States is more ahead in the technologies that underpin stockpile stewardship. Therefore, it remains in the U.S. interest to enforce a zero-yield standard in global nuclear test-ban efforts, because its adversaries would have more to gain by a resumption of testing.⁸¹

In the Cold War period, technology competition in weapons designs and delivery platforms went hand-in-hand. In the current environment, we see that technological advancements in nuclear delivery platforms and other domains are becoming more influential to the great powers' assessment of the nuclear balance. As noted earlier, the post-Cold War years have seen major leaps in accuracy, which dramatically increased the efficiency of delivery platforms. Advancements in navigation and guidance led to new smart weapons that can adjust their trajectory as they fly which makes it more difficult to intercept them. Innovations in scramjet engines have led to the development of hypersonic

78 Miller, "Stockpile Stewardship: What Were We Thinking? How Did It Work Out?" p. 14.

79 National Nuclear Security Administration, "The U.S. Nuclear Weapons Stockpile."

80 Ibid.

81 Péczeli and Goodwin, *Technical Issues in the Comprehensive Nuclear Test Ban Treaty (CTBT) Ratification Debate: A 20 Year Retrospective*, p. 19.

systems that challenge detection and defense due to their speed, maneuverability, and low altitude of flight. These developments in delivery platforms have a huge impact on strategic stability, and all three major powers are engaged in an intense competition to reap the benefits of these technological advancements. Russia's Avangard HGV (its new nuclear-armed, nuclear-powered torpedo) and the nuclear-powered, nuclear-armed intercontinental-range cruise missile are just some of the many examples of these trends.

The nuclear balance is also affected by technological advancements in other domains, such as remote sensing, conventional strike capabilities, anti-submarine warfare techniques, cyber operations, and counterspace developments.⁸²

In comparison to the Cold War period, legal, organizational, and bureaucratic structures also look very different today. In the Cold War, the Atomic Energy Commission was a small, streamlined organization that had wide authority to manage the nuclear weapons program and regulate the use of nuclear energy. When it was created, Congress gave the AEC extraordinary powers to execute its mission. On the one hand, this made the AEC a very effective organization that was able to implement "crash programs" to develop new capabilities in a short period of time, but on the other hand, these far-reaching powers also made the AEC a controversial organization. Finally, in 1974, the AEC was disbanded, and its functions were split between the Energy Research and Development Agency (ERDA, responsible for weapons development), and the Nuclear Regulatory Commission (NRC, responsible for nuclear regulations). A reorganization of ERDA led to the establishment of DOE in 1977, and NNSA was created under the DOE as a semiautonomous agency in 2000 that was responsible for the U.S. nuclear weapons complex and associated nonproliferation activities.⁸³

Unlike AEC, NNSA is a large bureaucratic organization that does not have regulatory powers. Its effectiveness is hindered by often unnecessary oversight from DOE, delayed and uncertain funding, limited national capacity for highly specialized construction and fabrication, and recruitment problems.⁸⁴ Safety and efficiency requirements and environmental regulations also often slow down progress and undermine flexibility. As a result of many of these factors, NNSA has become a risk-averse organization that reacts rather slowly to the changes of the security environment. In the past few years, NNSA started to ramp up its activities, and it has successfully delivered 200 modernized weapons to the Department of Defense (DOD) in 2023, which was the highest number since the end of the Cold War. At the same time, to meet the requirements of this competitive environment, scientists will probably need more intellectual freedom, which is only possible if fundamental changes happen that put an end to the self-censoring and pull-back culture of the past decades.⁸⁵

82 See more about these in Lieber and Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence."

83 Office of the Deputy Assistant Secretary of Defense for Nuclear Matters, *Nuclear Matters Handbook*.

84 Creedon, Kyl et al., "America's Strategic Posture—The Final Report of the Congressional Commission on the Strategic Posture of the United States," p. 55.

85 Brian McHale Cook, Gabrielle Frances Gundry, and Anna Péczeli, "Strategic Weapons in the 21st Century—Workshop Summary," Lawrence Livermore and Los Alamos National Laboratories (April 18, 2024). <https://cgsr.llnl.gov/sites/cgsr/files/2024-08/SW21-Workshop-Summary.pdf>. Accessed February 9, 2025.

How is Competition Different Today?

In general, technology competition has been a standard feature of the great powers' relationship since the dawn of the nuclear era. While the main characteristics of competition have shifted as the security environment underwent major changes, elements of competition were present even in the early 1990s, when the international community was rather optimistic about nuclear reductions and cooperation among the major powers. In this paper, I focused on the Cold War period and the post-2014 era, where competitive dynamics have generally been strong. Despite certain overlaps, there have been important differences in how competition unfolded in these two periods.

With regard to deterrence requirements, the goals of survivability and reliability have been key drivers of the Cold War competition, and they have remained relevant in today's security environment as well. However, a key difference is that it has become more difficult to meet these requirements in the current context. This is partly due to increased multipolarity, and partly due to technological advancements that have made this landscape significantly more complex. As a result, the burden for survivability has increased, and some of the old strategies, such as hardening, have become outdated in the current environment. These trends have also exacerbated vulnerability concerns in NC3 systems and introduced a number of new escalatory pathways.

On the flip side, technological developments have also played an important role in improving reliability and the ability to destroy hardened targets. In the Cold War, U.S. force requirements were mostly driven by Soviet nuclear forces. In contrast, today's environment is increasingly multipolar and multi-domain which means that Russian force levels are no longer the only factor in force structure decisions, and there is a bigger emphasis on tailored deterrence. These shifts reoriented technology competition towards seeking greater diversity and flexibility in nuclear delivery platforms and warhead types.

In the current environment, arms race dynamics also look very different from the Cold War years—so far, only U.S. adversaries have embarked on a pathway to increase the size and diversity of their nuclear stockpiles. The United States has just started to react to these changes, and given the limitations of its nuclear weapons complex, it will not be able to seek a massive nuclear buildup anytime soon.

Technology competition has also manifested differently than during the Cold War. There are huge asymmetries between the great powers' approach to competition—while Russia and China have focused on developing and fielding new and qualitatively better weapons designs, the United States put the emphasis on maintaining its legacy stockpile. These asymmetric objectives led to asymmetric strength—Russia and China enjoy marked advantages in nuclear weapons production, while the United States has a more technologically sound approach to stockpile stewardship. A key question in the future is whether the United States will be able to narrow some of these gaps, and whether it will be able to act at the speed of relevance.

There has also been a shift in the overall significance of certain areas. Since all major powers have acquired the ability to develop modern, miniature hydrogen bombs, technological developments in warhead designs are not as consequential as they were during the Cold War period. In the current environment, the main focus of competition is enabling greater resilience and flexibility that can positively impact overall competitiveness and improving the ability to maintain nuclear stockpiles without nuclear explosive testing.

As opposed to the Cold War period, the most influential technological advancements are primarily happening in delivery platforms and other domains. Greater accuracy and increased reliability have important implications for strategic stability. Developments in the new military domains have also gained increased significance in the great powers' assessment of the strategic balance, and countering these developments can be a costly and technologically daunting task.

Lastly, political, bureaucratic, and organizational factors have always been an important aspect of technology competition. The United States has traditionally enjoyed great advantages in this regard due to its individualistic and entrepreneurial culture, free market economy, and democratic political system. These factors have facilitated intellectual freedom and innovation. While all of these remain important sources of strength, the current nuclear weapons complex is burdened by often unnecessary bureaucratic procedures, over-regulation, domestic political disputes, and a risk-averse attitude, which have undermined U.S. competitiveness and made it more difficult to quickly react to the changes in the security environment.

Altogether, these new trends suggest that what we see today is not an unfolding arms race, but instead an intensifying technology competition with 21st century characteristics. These characteristics entail new challenges and problems that require new approaches and solutions.

Policy Implications

Although the end of the Cold War was followed by major reductions in nuclear forces and reduced tensions between the great powers, the legacy of the nuclear arms race continues to shape international security. Technology competition in the Cold War has led to major advancements in the fields of physics, engineering, and computer science. These scientific achievements have played a key role in the development of novel technologies that pose new challenges to the concept of stability based on mutual vulnerability. Since the United States has been at the forefront of many of these technologies, its adversaries have launched a new competition to close the gaps and get ahead.

As a result of these developments, deterrence requirements are shifting, and the United States has been forced to change course and rethink its approach. While the consequences of many of these new technologies are still uncertain, continued nuclear buildup by adversaries could have a significant effect on the military balance. Therefore, the United States cannot just sit by while its adversaries have been racing for years. As Colin Gray noted, "an arms race is not the worst of all possible worlds. For example, one obvious alternative to an arms race can be a situation wherein only one party is 'racing.' History is not unduly eloquent on the benefits to the general security of an imbalance of military power."⁸⁶ While I agree that a certain response is needed, I also argue that it does not need to be a new arms race.

An arms race in the current security environment would be an extremely challenging path forward. A new three-way arms race with Russia and China would put a huge financial and economic burden on the United States. Given the asymmetries between Russian and Chinese capabilities, the United States would need to compete in a wide range of areas. Achieving superiority across the board (which is the only winning condition under the zero-sum logic of an arms race) would be almost impossible.

⁸⁶ Gray, "The Urge to Compete: Rationales for Arms Racing," p. 208.

Besides, in such a three-way arms race, the chances of misunderstandings and inadvertent escalation would potentially be much higher than during the bipolar competition of the Cold War.

Embarking on this path would take a long time. After decades of neglect, the nuclear production enterprise is in the process of recapitalization with new facilities and new manufacturing capabilities underway. However, the focus of these efforts is rebuilding legacy capabilities and facilities to meet the needs of the current program of record.⁸⁷ Entering a new arms race would require a dramatic transformation of the entire enterprise that would probably take decades given the infrastructure needs that such a process would entail. Therefore, in the coming years, a nuclear arms race is not a realistic option for the United States.⁸⁸

This, however, does not necessarily place the United States at a disadvantage, because there are other, better alternatives to a nuclear arms race. The United States does not need to match adversary capabilities one-for-one to remain competitive. As the current directors of the three nuclear weapons laboratories, Kimberly Budil, Thom Mason, and James Peery note, the United States “need not compete on Russian and Chinese terms, seeking both quantitative and qualitative improvements. It should compete on its own terms recognizing the inherent strengths and weaknesses of our position.”⁸⁹ Since 1945, the United States has built up a number of important strategic advantages through innovation (e.g., dominance in the space domain, superior situational awareness, or undersea warfare). So far, adversaries have not been able to match these advantages, and in some cases, Russia and China are decades away from catching up.⁹⁰ Maintaining a superior position in these areas could prove more impactful than simple numerical equivalence in nuclear capabilities.⁹¹ Therefore, technology competition should focus on protecting existing advantages and trying to build new ones.

In terms of nuclear capabilities, the United States should focus on maintaining approximate strategic equivalence, enabled by a more responsive nuclear weapons complex. Instead of outcompeting adversaries in every capability, this path would require a nuclear force posture with robust and flexible options across a range of capabilities (potentially including a modest number of

87 Kimberly S. Budil, Thom Mason, and James Peery, “The Nuclear Security Enterprise at the Inflection Point,” in Brad Roberts and William Tobey, eds., *The Inflection Point and the U.S. Nuclear Security Enterprise*, Center for Global Security Research Occasional Papers (Livermore, CA: Lawrence Livermore National Laboratory, October 2023), pp. 33–37. <https://cgsr.llnl.gov/sites/cgsr/files/2024-08/CGSR-Inflection-OP-FullBook-10-04-2023-v4-Web.pdf>. Accessed February 9, 2025.

88 Anna Péczeli et al., “Long-Term Competition and Nuclear Deterrence,” CGSR Workshop Summary, Center for Global Security Research (December 2023). <https://cgsr.llnl.gov/content/assets/docs/Intrawar-Deterrence-Workshop-Summary.pdf>. Accessed February 9, 2025.

89 Kimberly S. Budil, Thom Mason, and James Peery, “Toward a More Competitive U.S. Approach,” in Brad Roberts, ed., *Stockpile Stewardship in an Era of Renewed Competition* (Livermore, CA: Lawrence Livermore National Laboratory, April 2022), pp. 68–71. https://cgsr.llnl.gov/sites/cgsr/files/2024-08/cgsr_occasional_stockpile-stewardship-era-renewed-competition.pdf. Accessed February 9, 2025.

90 Péczeli et al., “Long-Term Competition and Nuclear Deterrence.”

91 Austin Long and Brendan Rittenhouse Green, “Stalking the Secured Second Strike: Intelligence, Counterforce, and Nuclear Strategy,” *Journal of Strategic Studies* 38, no. 1-2 (2015), p. 40.

new capabilities). Achieving this robust and flexible force posture rests on a more competitive U.S. approach to stockpile stewardship and nuclear weapons production. This entails

a nuclear security enterprise that has the innovative acumen, technological adaptiveness, production efficiency, and manufacturing scalability of America's world-leading private sector manufacturers. We imagine an end-to-end acquisition process that enables responses to technical or geopolitical surprise rapidly enough to be strategically relevant.⁹²

Making these adjustments would help the United States respond to the deterioration of the security environment and hedge against future uncertainties, while also disincentivizing arms racing by adversaries.

92 Budil, Mason, and Peery, "Toward a More Competitive U.S. Approach," p. 69.

Great Power Competition and Asymmetry: Why Countering Strategic Advantages in the Military Domain is As Critical As Emulating Them

Eleni G. Ekmektsioglou

Introduction

Both the academic literature and policy analysis pieces have focused on questions that pertain to symmetrical great power competition in the military domain in pursuit of strategic advantages.⁹³ With the emphasis on the drivers behind rising powers' attempts to adopt established powers' military practices or advanced weapons systems, scholars and policy experts have tried to explain great power competition through the analytical frames of emulation; what I call symmetrical competition.⁹⁴ This over-emphasis on emulation has led scholars and policy pundits to assume that rising powers would embrace asymmetric competition *only* when emulation is regarded as unattainable. In other words, incapacity to emulate due to financial, organizational or technological factors would lead a rising power to the second-best option; asymmetric competition through countering. This way, asymmetry is portrayed as a choice dictated by lack of capacity, a last resort option when emulation cannot be achieved.⁹⁵ The main reason behind the literature's emphasis on symmetrical competition through emulation has been the tendency to equate emulation only to higher levels of military effectiveness production. Through this analytical lens, scholars have argued that the United States enjoys a solid and uncontested strategic advantage in the military domain in the foreseeable future given the

93 Andrew Scobell, Michael McMahon, and Cortez A. Cooper, "China's Aircraft Carrier Program: Drivers, Developments, Implications," *Naval War College Review* 68, no. 4 (2015), pp. 64–79; Michael Beckley, "The Emerging Military Balance in East Asia: How China's Neighbors Can Check Chinese Naval Expansion," *International Security* 42, no. 2 (2017), pp. 78–119; Louis Bearn and Nick Childs, "China's Aircraft Carriers Begin to Spread Their Wings," *Military Balance Blog*, IISS (November 2024), <https://www.iiss.org/online-analysis/military-balance/2024/11/chinas-aircraft-carriers-begin-to-spread-their-wings/> (accessed March 30, 2025); "Russia and China Still Can't Compare to America's Military Power, According to the Latest Rand Report," *Popular Mechanics* (October 19, 2021), <https://www.popularmechanics.com/military/a37953556/russia-china-military-cooperation-rand-report/> (accessed March 30, 2025); Maya Carlin, "China's J-20 Fighter Makes U.S. Air Force Generals Freak Out," Text, *The National Interest* (The Center for the National Interest, July 26, 2024), <https://nationalinterest.org/blog/buzz/chinas-j-20-fighter-makes-us-air-force-generals-freak-out-210421>. (accessed March 30, 2025).

94 Andrea Gilli and Mauro Gilli, "The Diffusion of Drone Warfare? Industrial, Organizational, and Infrastructural Constraints," *Security Studies* 25, no. 1 (January 2, 2016), pp. 50–84, <https://doi.org/10.1080/09636412.2016.1134189> (accessed March 30, 2025); Michael Beckley, "China's Century? Why America's Edge Will Endure," *International Security* 36, no. 3 (2012), pp. 41–78, http://www.mitpressjournals.org/doi/abs/10.1162/ISEC_a_00066 (accessed March 30, 2025); Stephen G. Brooks and William C. Wohlforth, "The Rise and Fall of the Great Powers in the Twenty-First Century: China's Rise and the Fate of America's Global Position," *International Security* 40, no. 3 (January 2016), pp. 7–53, https://doi.org/10.1162/ISEC_a_00225 (accessed March 30, 2025); Stephen G. Brooks and William C. Wohlforth, "The Once and Future Superpower: Why China Won't Overtake the United States," *Foreign Affairs* 95 (2016), p. 91. <https://www.jstor.org/stable/43946860> (accessed March 30, 2025).

95 Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences for International Politics* (Princeton, NJ: Princeton University Press, 2010); Thomas G. Mahnken, "Uncovering Foreign Military Innovation," *Journal of Strategic Studies* 22, no. 4 (December 1, 1999), pp. 26–54 (accessed March 30, 2025).

constantly rising complexity of modern military technology that makes emulation a daunting task.⁹⁶

Having said that, however, the aforementioned assumption that pertains to a rising power's hierarchy choices can be misleading and misrepresent the empirical world. In fact, countering instead of emulating could be considered as the first choice by a rising power under certain conditions when pursuing military effectiveness in options other than just emulation and symmetrical competition could appear to be a cost effective and strategically salient choice. Put differently, one could hypothesize that a rising power in competition with an established adversary is faced with the following two choices: either emulate the competitor's military practices and preferred way of war (symmetrical competition) or seek to cancel its competitor's strategic advantages in the military domain through asymmetrical means. In this paper, therefore, I argue that by focusing our attention on symmetrical competition in pursuit of strategic advantages in the military domain, we tend to overlook cases where a rising power chooses to develop and deploy weapons, platforms, operational concepts, or strategies in order to negate and cancel the established power's strategic advantages instead of trying to imitate them. I call this type of asymmetrical competition "countervention."⁹⁷ To be fair, grasping the dynamics and drivers behind symmetrical great power competition is of critical importance. However, our understanding and predictive capacity will remain incomplete unless we explore asymmetrical attempts that a rising power might pursue against the established state's strategic advantages in the military domain. Studying this alternative form of military competition through the concept of countervention will help us grasp regional military balances in a more accurate way and come up with more realistic predictions and answers to questions such as military effectiveness production, battle initiation, number of casualties, or conflict duration. Consequently, the core of this paper will look at the drivers behind a rising power's choice to pursue asymmetrical competition through countering in an effort to shed some light on the drivers behind this understudied but frequently empirically observed phenomenon.

The rest of the paper proceeds in the following way: First, I examine the reasons behind both scholars' and policy experts' emphasis on emulation and symmetrical competition and explain why our over-emphasis on emulation can be misleading. Then I turn to the main concept and objective of this paper which is the definition of the term "asymmetrical competition" through a rising power's deliberate choice of countering the established power's strategic advantages in the military domain. I offer three indicators whose presence should incentivize a rising power to prioritize asymmetric competition over emulation. I conclude with some policy recommendations that aim to disassociate the choice of asymmetry with weakness or conventional inferiority, or financial or organizational

96 "Why China Cannot Challenge the US Military Primacy," *Journal of Indo-Pacific Affairs*, Air University Press (December 13, 2021). <https://www.airuniversity.af.edu/JIPA/Display/Article/2870650/why-china-cannot-challenge-the-us-military-primacy/#:~:text=China's%20military%20faces%20institutional%20shortcomings,air%20defense%20and%20antisubmarine%20warfare>. Accessed March 30, 2025.

97 Bruce W. Bennett, Christopher P. Twomey, and Gregory F. Treverton, *What Are Asymmetric Strategies?* (Santa Monica, CA: RAND, 1999).

incapacity, which could pave the way for policy analysis that is creative, clear-eyed and well-tailored to the U.S.-China military balance.⁹⁸

The Fog of Peace and the Reasons Behind the Disproportionate Emphasis on Emulation Over Counter Strategies

As a matter of fact, since the end of the Cold War and the very beginning of the emerging U.S.-China competition, policy pundits and scholars have expected Chinese strategists to invest in technologies and ways of war that emulate their technologically superior competitor, the U.S. military.⁹⁹ After the 1991 Iraq war and the Kosovo Allied Force Operation, the military advantages of information warfare, which the United States was trying to master, became obvious to both friends and competitors.¹⁰⁰ In fact, China did appreciate the lessons from the just-mentioned campaigns and invested heavily in what Chinese decisionmakers called “informationized warfare” in an effort to emulate American military practices and technologies.¹⁰¹ The same was the case in other realms of strategy such as in the air or sea domains. A great deal of attention was devoted to China’s efforts to copy U.S. technologies in its process of creating its own fifth-generation aircraft while the refurbishing of an old Ukrainian aircraft carrier was what convinced many China observers that the People’s Liberation Army Navy (PLAN) was indeed in search of regional dominance through sea control.¹⁰²

It was the focus on China’s emulation efforts that led some scholars and policy pundits to claim that U.S. military supremacy will endure in the foreseeable future. The argument was predicated on very sophisticated and masterly developed analyses that pertained to the technological complexity of the information age weapons systems where systems integration-related challenges (among others)

98 The main reason behind this association of asymmetry to military weakness, or the lack of financial or organizational means is mainly due to the fact that the concept of asymmetry is deeply embedded in the counterterrorism or counterinsurgency literature. For some examples see, Michael J. Mazarr, “The Folly of ‘Asymmetric War,’” *Washington Quarterly* 31, no. 3 (2008), pp. 33–53; Eugene Miakinkov, “The Agency of Force in Asymmetrical Warfare and Counterinsurgency: The Case of Chechnya,” *Journal of Strategic Studies* 34, no. 5 (October 1, 2011), pp. 647–80; John A. Nagl and Peter J. Schoomaker, *Learning to Eat Soup with a Knife: Counterinsurgency Lessons from Malaya and Vietnam*, 1st edition (Chicago, IL: The University of Chicago Press, 2005); Ehsan Ahrari, “Transformation of America’s Military and Asymmetric War,” *Comparative Strategy* 29, no. 3 (August 6, 2010), pp. 223–44; and Ivan Arreguín-Toft, “How the Weak Win Wars: A Theory of Asymmetric Conflict,” *International Security* 26, no. 1 (July 1, 2001), pp. 93–128.

99 David C. Logan, “China’s Future SSBN Command and Control Structure,” Strategic Forum, INSS, National Defense University (November 2016), <https://inss.ndu.edu/Portals/68/Documents/stratforum/SF-299.pdf?ver=2016-11-28-093723-680> (accessed March 30, 2025); Scobell et al., “China’s Aircraft Carrier Program;” Scobell, McMahan, and Cooper; Abraham Abrams, *China’s Stealth Fighter: The J-20 “Mighty Dragon” and the Growing Challenge to Western Air Dominance* (Barnsley, South Yorkshire: Pen and Sword Books 2024); Oriana Skylar Mastro, *Upstart: How China Became a Great Power* (New York, NY: Oxford University Press, 2024).

100 Scholars and policy pundits called it the Revolution in Military Affairs, see Eliot A. Cohen, “Change and Transformation in Military Affairs,” *Journal of Strategic Studies* 27, no. 3 (September 1, 2004), pp. 395–407.

101 Toshi Yoshihara, *Chinese Information Warfare: A Phantom Menace Or Emerging Threat?* (DIANE Publishing, 2001); Yoshiaki Sakaguchi and Mayama Katsuhiko, “Significance of the War in Kosovo for China and Russia,” *NIDS Security Reports*, no. 3 (March 2002), pp. 1–23, https://www.nids.mod.go.jp/english/publication/kiyo/pdf/bulletin_e2001_1.pdf (accessed March 30, 2025).

102 Scobell et al., “China’s Aircraft Carrier Program.”

make emulation a deeply daunting task.¹⁰³ As convincing and meticulous as their analyses were, what was usually overlooked or labeled as "less consequential" was the fact that China channeled resources, intellectual thinking, and innovative ideas towards weapons, tactics, operational concepts, and strategies that sought not to emulate but to cancel the strategic advantages an adversary could reap from the application of information or network-centric warfare.

If the observed empirical reality pointed towards the systematic theorizing and understanding of not just emulation, then why did other choices that a military might be presented with remain in the dark and under-theorized? Let me start by saying that the main reason behind such an unbalanced focus on emulation is the well-established (and almost unquestionable) equation of emulation that a military might assign to higher levels of military effectiveness.¹⁰⁴ The argument goes on in the following way: if emulation is depicted as the right choice for all competitors, then the option of asymmetric competition takes place only when the competitor is either organizationally, financially, or technologically incapable of emulating its competitors' successful military practices.¹⁰⁵ This way, asymmetric competition through countering is judged to be less consequential or powerful as a strategy compared to emulation. In fact, the equation of technological emulation to military effectiveness is a thesis deeply influenced by the field's technological determinism that is embedded in both academic and policy works.¹⁰⁶ Along these lines, traditional Realist work would argue that new technologies are to be emulated by all actors given their potential to increase power leading to what they call "competitive homogenization."¹⁰⁷ In other words, all rational and security seeking actors would make the choice to emulate new technologies in pursuit of survival. According to Kenneth Waltz, "Contending states imitate the military innovations contrived by the country of greatest capability and ingenuity."¹⁰⁸ This widespread emulation would eventually lead to what Waltz called "competitive homogenization." This technologically deterministic approach puts the emphasis on technological emulation regarding it as the *sine qua non* for military effectiveness leaving outside of

103 Stephen G. Brooks and William C. Wohlforth, "The Rise and Fall of the Great Powers in the Twenty-First Century: China's Rise and the Fate of America's Global Position," *International Security* 40, no. 3 (January 2016), pp. 7–53; Stephen G. Brooks and William C. Wohlforth, "The Once and Future Superpower: Why China Won't Overtake the United States," Stephen G. Brooks and William C. Wohlforth, "The Myth of Multipolarity: American Power's Staying Power," *Foreign Affairs* 102 (2023), p. 76; Andrea Gilli and Mauro Gilli, "Why China Has Not Caught Up Yet: Military-Technological Superiority and the Limits of Imitation, Reverse Engineering, and Cyber Espionage," *International Security* 43, no. 3 (February 1, 2019), pp. 141–89.

104 Kenneth N. Waltz, *Theory of International Politics*, 1st edition (Long Grove, IL: Waveland Press Inc, 2010); Joao Resende-Santos, *Neorealism, States, and the Modern Mass Army* (New York, NY: Cambridge University Press, 2007).

105 Michael C. Horowitz, *The Diffusion of Military Power: Causes and Consequences for International Politics* (Princeton, NJ: Princeton University Press, 2010); Andrea Gilli and Mauro Gilli, "Why China Has Not Caught Up Yet: Military-Technological Superiority and the Limits of Imitation, Reverse Engineering, and Cyber Espionage."

106 Harvey M. Sapolsky and Jeremy Shapiro, "Casualties, Technology, and America's Future Wars," *The US Army War College Quarterly: Parameters* 26, no. 2 (1996), p. 10; Thomas G. Mahnken, *Technology and the American Way of War* (New York, NY: Columbia University Press, 2008); Michael E. O'Hanlon, *Technological Change and the Future of Warfare* (Washington DC: Brookings Institution Press, 2011); Max Boot, "The New American Way of War," *Foreign Affairs* 82, no. 4 (2003), pp. 41–58.

107 Waltz, *Theory of International Politics*. p. 127.

108 Ibid.

the scope of its attention critical factors such as operational adroitness or cost imposing strategies through the use of less technologically developed means.¹⁰⁹

It should be highlighted, therefore, that this conventional wisdom needs to be subjected to the highest of empirical scrutiny instead of accepting its validity unquestionably.¹¹⁰ Pushing back against the technological determinism and the over-emphasis on symmetric competition through emulation, I find interest in bringing back from the antiquity and Byzantine era the idea of intellectualism in warfare.¹¹¹ For centuries, strategists fought wars with the conviction that cunning stratagems, rules, and techniques of war could produce military effectiveness even against quantitatively stronger enemies.¹¹² Generations of soldiers were educated in a way that saw war more as an art where operational intellectualism was the road to victory looking up to personalities like Themistocles from the sea battle of Salamina or Miltiades from the battle of Marathon, as well as more contemporary strategists such as Roman Hannibal or French Napoleon.¹¹³ A common characteristic of the “strategic intellectualism” argument era is that strategists sought, first and foremost, to offset the enemy’s advantages through the application of countermeasures or new operational thinking instead of entangling themselves into a symmetric arms race with their opponent.¹¹⁴ At the beginning of the industrial era with the gradual mechanization of armed forces, operational intellectualism as a force multiplier was replaced by a focus on technology in academia as well as in the policy/defense worlds, dismissing cases of operational creativity because they were not technocratic enough for the technological deterministic bias that defined both worlds.¹¹⁵ Research that dominated the field sought to understand the determinants behind organizations that managed to solve the mystery

109 Thomas G. Mahnken, “Cost-Imposing Strategies.” Center for a New American Security (Washington, DC: November 18, 2014), <https://www.cnas.org/publications/reports/cost-imposing-strategies-a-brief-primer> (accessed March 30, 2025); Stephen Biddle, “The Past as Prologue: Assessing Theories of Future Warfare,” *Security Studies* 8, no. 1 (September 1, 1998), pp. 1–74.

110 Gilli and Gilli, “The Diffusion of Drone Warfare?;” Andrea Gilli and Mauro Gilli, “The Spread of Military Innovations: Adoption Capacity Theory, Tactical Incentives, and the Case of Suicide Terrorism,” *Security Studies* 23, no. 3 (July 3, 2014), pp. 513–47; Eugene Gholz, “Globalization, Systems Integration, and the Future of Great Power War,” *Security Studies* 16, no. 4 (December 6, 2007), pp. 615–36; Brooks and Wohlforth, “The Rise and Fall of the Great Powers in the Twenty-First Century.”

111 Colin S. Gray, *Weapons of Strategic Effect: How Important Is Technology?* Center for Strategy and Technology, Air War College, no. 21 (2012), <https://apps.dtic.mil/sti/pdfs/ADA407083.pdf> (accessed March 30, 2025); Colin S. Gray, *Weapons Don’t Make War: Policy, Strategy, and Military Technology* (Lawrence, KS: University Press of Kansas, 1993), p. 3.

112 Athanasios G. Platias and Kōnstantinos Koliopoulos, *Thucydides on Strategy: Grand Strategies in the Peloponnesian War and Their Relevance Today* (New York, NY: Columbia University Press, 2010); Walter W. Kaegi Jr, *Some Thoughts on Byzantine Military Strategy* (Brookline, MA: Holy Cross Press, 1983).

113 For a chapter in this report that makes a similar argument, see Dustin Ray League, “Adaptation Advantage.”

114 Edward N. Luttwak, *The Grand Strategy of the Byzantine Empire* (Cambridge, MA: Harvard University Press, 2011); Charalambos Papatotiriou, *Byzantine Grand Strategy* (Stanford, CA: Stanford University, 1991).

115 Russell Frank Weigley, *The American Way of War: A History of United States Military Strategy and Policy* (Bloomington, IN: Indiana University Press, 1977).

of a new technology by using it in an “optimal” way in the battlefield.¹¹⁶ The goal was innovation; a term always positively charged and defined through the solving of the machine mystery. Such an approach, however, elevates a certain technology to the extent that is portrayed as the key to military effectiveness leaving little space for exploration of counters that could exploit the dominant power’s vulnerabilities.¹¹⁷

That said, nevertheless, a number of cases from modern warfare suffice to expose the limits of the argument’s explanatory power. Just an illustrative example: the Egyptian AT-3 Sagger anti-tank guided missile (ATGM) and the development of new operational concepts for its application against the Israeli powerful and highly maneuverable tanks caused heavy casualties to the Israeli forces; an unexpected development that took the Israelis by surprise in 1973. Another example from a forgotten case of success during WWI: the Italian Navy scored an impressive victory against its superior Austrian Navy through the use of “humble” torpedo boats as countermeasures against the Austrian Navy’s battlefleet. Interestingly, the only battleship that was sunk during WWI was the Austrian Szent István that was lethally hit by an Italian MAS boat.¹¹⁸ If asymmetric competition through countering has the potential to be consequential in the military domain, then why do policy makers and practitioners tend to emphasize symmetric competition? In other words, apart from the scholarly tendency to equate emulation to higher levels of military effectiveness, what are some other obstacles in the policy world that prevent policymakers and analysts from discerning, detecting, tracking, and analyzing a competitor’s asymmetric strategies through countering?

I will start by highlighting that asymmetric competition can be easily detected but, nevertheless, can be equally easily misunderstood or misperceived. Intelligence can discern efforts to develop countermeasures against the established power’s main weapons and/or technologies. However, the actual operationalization and integration of these countermeasures into the competitor’s tactics and operational plans is what will dramatically impact the actual military effectiveness of the asymmetric strategy.¹¹⁹ Detecting efforts to counter is one thing. Understanding the context within which countermeasures will be operationalized and used at the tactical and operational levels is quite another and a much trickier exercise. For instance, and in relevance with the aforementioned Egyptian application of its ATGMs, it needs to be highlighted that the Israelis were aware of the weapon and they deeply understood its characteristics and performance potential in the theater of operations. In fact, the Israelis had a very similar weapon in their arsenal and yet they failed to appreciate

116 Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca, NY: Cornell University Press, 1994); Williamson R. Murray and Allan R. Millett, *Military Innovation in the Interwar Period* (Cambridge: Cambridge University Press, 1998); Owen R. Cote Jr., “The Third Battle: Innovation in the U.S. Navy’s Silent Cold War Struggle with Soviet Submarines,” Newport Paper no. 16 (2003), <https://apps.dtic.mil/sti/tr/pdf/ADA421957.pdf> (accessed March 30, 2025); Emily O. Goldman and Richard B. Andres, “Systemic Effects of Military Innovation and Diffusion,” *Security Studies* 8, no. 4 (June 1999), pp. 79–125; and Adam N. Stulberg, “Managing Military Transformations: Agency, Culture, and the U.S. Carrier Revolution,” *Security Studies* 14, no. 3 (April 2005), pp. 489–528.

117 Peter J. Katzenstein, *Cultural Norms and National Security: Police and Military in Postwar Japan* (Ithaca, NY: Cornell University Press, 2018).

118 Luigi Donolo and James J. Tritten, “The History of Italian Naval Doctrine,” Naval Doctrine Command (June 13, 1995). <https://apps.dtic.mil/sti/tr/pdf/ADA296628.pdf>. Accessed March 30, 2025.

119 Stephen Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, NJ: Princeton University Press, 2010).

Egyptian intentions with regard to the actual operationalization of their anti-tank missiles.¹²⁰ In other words, emulation is detectable and understood rapidly because it is familiar. Countering, however, can be detected but great effort needs to be invested in making sense of it through the eyes of the competitor and without self-projection on the other's intentions and preferred ways of war.¹²¹

Analysis can become even trickier, paradoxically, due to the plethora of information and the necessary heuristics one needs to count on in order to make sense of what is observed. Information about a competitor can be plenty, and it can come from various sources. However, a lot of information does not mean less uncertainty. In fact, given the great amount of intel noise, organizations develop practices that point analysts to the pieces of intelligence that are judged as important.¹²² During peacetime and periods of high uncertainty, organizations and especially state bureaucracies aim at uncertainty reduction through the production of "truths" or "facts" about the competitor's character, intentions, or preferred ways of war. In order to avoid feeling overwhelmed by the plethora of intelligence or by the big numbers of variables in our social world, analysts bring to the interpretation their own heuristics, such as preconceptions, ideas on what the next war would look like, and how emerging technologies should be used optimally.¹²³ Especially during periods of technological fluidity and characterized by the promises of emerging technologies whose maturation horizon is questionable, organizations tend to look for answers in areas they are interested in exploring further themselves or their decisionmakers are focused on.¹²⁴ As Thomas Mahnken explains, "as a result, intelligence organizations more frequently identify foreign developments that mirror those of their own armed forces than those that differ substantially from them."¹²⁵

The use of heuristics such as cognitive frames or preconceptions in the process of uncertainty reduction by intelligence analysts or strategists is necessary for the production of any sort of verdict that policy will be based on, to be clear. It is a neurological defense mechanism against the chaos of our social world, and it is a valuable one if we want to remain functional thinkers. At the same time, however, the need to reduce uncertainty through the production of widely acceptable "facts" could lead to overconfidence in our conclusions, group thinking, and cognitive dissonance. Cognitive frames are necessary, but self-reflection as well as frequent checking of our pre-conceptions or of our line of thinking/reasoning is even more critical if we want to make good use of the information at our disposal in avoidance of tragic intelligence or strategy mistakes.

Military history is replete with cases where intelligence organizations had all relevant information but failed to put all the parts of the puzzle together, which led them to false conclusions regarding their competitors' intentions or war plans. During the Cold War, U.S. strategists saw Soviet nuclear

120 Michael Eisenstadt and Kenneth M. Pollack, "Armies of Snow and Armies of Sand: The Impact of Soviet Military Doctrine on Arab Militaries," *Middle East Journal* 55, no. 4 (2001), pp. 549–78.

121 Robert B. Bathurst, *Intelligence and the Mirror: On Creating an Enemy*, 1st edition (London: SAGE Publications Ltd, 1993).

122 Joshua Rovner, *Fixing the facts: national security and the politics of intelligence* (Ithaca, NY: Cornell University Press, 2011).

123 Keren Yarhi-Milo, "In the Eye of the Beholder: How Leaders and Intelligence Communities Assess the Intentions of Adversaries," *International Security* 38, no. 1 (July 2013), pp. 7–51.

124 Thomas G. Mahnken, "Uncovering Foreign Military Innovation," *Journal of Strategic Studies* 22, no. 4 (December 1, 1999), p. 17.

125 Ibid.

strategy and posture as a reflection of U.S. nuclear practices.¹²⁶ Another famous case is the interwar efforts of the U.S. Naval Intelligence to decipher the Imperial Japanese Navy's plans for carrier operations which was conceived by the Imperial Japanese Navy as a counterstrategy against the U.S. battlefleet. Even though U.S. intelligence had a plethora of information on the Japanese technological progress with regard to the aircraft carrier, it failed to assess and evaluate correctly Japan's plans for surface warfare that aligned more with denial-focused concepts of operations instead of Mahanian axioms of sea control.¹²⁷ The role of the torpedo and the neglect the U.S. Navy showed to the weapon and its potential is illustrative of the limitations of organizational preconceptions when a competitor's countermeasures are examined. In fact, during the Interwar period, U.S. Navy damage assessments of the new long-range torpedo, which could carry heavier ordnance, required the formulation of ad hoc scientific boards. The boards produced a number of conclusions on the expected performance of the new weapon claiming that they were based purely on technical estimations.¹²⁸ Their deliberations and scientific assessments of the torpedo's potential damage against armored battleships, however, underestimated the actual potential of the new weapon and relied on assumptions about former versions of the torpedo technology. Needless to say, wargame results were inaccurate and led to the premature dismissal of a very consequential weapon for WWII.¹²⁹

In a nutshell, two main drivers lie behind the "emulation over-emphasis" in both academia and the policy world:

- a. the conventional, albeit, questionable argument that regards emulation as the only key to higher military effectiveness and, therefore, portrays countering as a less powerful way of war; and
- b. organizational cognitive limitations that lead intelligence organizations to recognize what is familiar while overlooking what appears to be intelligible or unfamiliar, *prima facie*. These are the main reasons behind the over-theorizing of symmetric competition in academia and the over-emphasis of emulation in the policy world while leaving asymmetric competition understudied and under-explained.

Asymmetric Competition: Typology and the Drivers Behind a Competitor's Choice to Counter its Adversary's Strategic Advantages in the Military Domain

The previous section explained the reasons behind policy experts' and scholars' focus on the concept of emulation as well as the organizational cognitive obstacles towards the detection and comprehension of asymmetric competition. In this section, I will offer a typology of asymmetric competition and the countering options a rising power could draw from. I will then go through the conditions under which a rising competitor could feel more compelled to prioritize countering over emulation strategies.

126 Thomas G. Mahnken, *Uncovering Ways of War: U.S. Intelligence and Foreign Military Innovation, 1918–1941*, 1st edition (Ithaca, N.Y.; Bristol: Cornell University Press, 2009).

127 Ibid.

128 John M. Lillard, *Playing War: Wargaming and U.S. Navy Preparations for World War II* (Lincoln, NE: University of Nebraska Press, 2016); Robert L. O, *Sacred Vessels: The Cult of the Battleship and the Rise of the U. S. Navy: 1st Edition* (New York, NY: Oxford University Press, USA, 1994).

129 John M. Lillard, *Playing War: Wargaming and U.S. Navy Preparations for World War II* (Lincoln, NE: University of Nebraska Press, 2016).

Starting from the definition of the term “asymmetric,” the 1999 Joint Strategy Review by the U.S. Department of Defense (DOD) defines asymmetric approaches as “attempts to circumvent or undermine U.S. strengths while exploiting U.S. weaknesses, using methods that differ significantly from the United States’ expected method of operations.”¹³⁰ The term puts the emphasis on two things: first, it is important to note that asymmetry implies the development of ways of war that are unexpected and deeply different from the ones that the established power employs. Second, through asymmetry, the competitor seeks to seize the initiative capitalizing on its own strengths while taking advantage of the established power’s blind spots or weaknesses. In other words, asymmetry does not mean the countering of the enemy’s strategic advantages through incrementalism (Cold War Arms Race) but through the use of unexpected weapons, tactics, concepts, or operations that create new terms to the game. According to Steven Metz and Douglas Johnson’s definition, asymmetry is acting, organizing, and thinking differently than opponents in order to maximize one’s own advantages, exploit an opponent’s weakness, attain the initiative, or gain greater freedom of action— the exploitation of the initiative.¹³¹ Experts usually refer to this type of offensive using the Clausewitzian concept “center of gravity” which is, however, inaccurate. By “center of gravity,” Clausewitz meant the enemy’s armed forces which alludes to a war of attrition of the enemy’s means to protect himself/herself and keep using violence.¹³² Asymmetric countering is more closely linked to John Warden’s System of Systems theory¹³³ or B. H. Liddell Hart’s¹³⁴ concept of “indirect approach,” if we had to anchor it in the literature of military thinking. The reason behind my connection of the asymmetric approach to either John Warden or B. H. Liddell Hart is the following: Clausewitz’s center of gravity implies that victory means the destruction of the enemy’s armed forces, which renders the enemy incapable of continuing the fight. Asymmetry, on the other hand, differs by targeting the enemy’s vulnerable points, which implies a different theory of victory or a different way of thinking about conflict. The competitor does not seek to assert dominance or the overall destruction of the enemy’s armed forces, but rather the imposition of cost on the enemy through cancelling its strategic advantages while, at the same time, exploiting its vulnerabilities.

It needs to be highlighted that based on the definitions found in the policy and scholarly literature, there is nothing inherent to the term “asymmetry” that should allude directly to the competition between a powerful actor and a weaker one, even though after 9/11 that was the semantic core of

130 *Joint Strategy Review 1999*, Washington, DC: The Joint Staff (1999), p. 2.

131 Douglas V. Johnson, and Steven Metz. *Asymmetry and US military Strategy: Definition, Background, and Strategic Concepts* (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, 2001).

132 Peter Paret, *Clausewitz and the State: The Man, His Theories, and His Times* (Princeton, NJ: Princeton University Press, 2007); Antulio Joseph Echevarria, *Clausewitz’s Center of Gravity: Changing Our Warfighting Doctrine--Again!* (Strategic Studies Institute, U.S. Army War College, 2002).

133 John Andreas Olsen, *John Warden and the Renaissance of American Air Power* (Washington, DC: Potomac Books, Inc., 2007).

134 R. A. Mason, “Sir Basil Liddell Hart and the Strategy of the Indirect Approach,” *Royal United Services Institution Journal* 115, no. 658 (June 1, 1970), pp. 37–41; Basil Liddell Hart, “*Strategy: The Indirect Approach*,” in Thomas G. Mahnken and Joseph A. Maiolo, (eds.), *Strategic studies: A reader* (London, U.K.: Routledge, 2008).

the term.¹³⁵ Extrapolated in the current context of great power competition, the term “asymmetry” can be especially significant from an explanatory point of view. If we disassociate it from the strong/weak binary and instead emphasize the element of surprise, asymmetry of means, and the intention to cancel the established power strategic advantages through the exploitation of blind spots in its theory of victory or technological apparatus of war, then the concept sheds light on a number of aspects of the current U.S.-China competition.¹³⁶

Drawing on some historical examples from naval strategy in order to show that asymmetry should be disassociated from the powerful/weak dichotomy, traditionally the creation of big battlefleets that sought to impose control of the sea was deemed to be the strategy of powerful naval forces whereas sea denial through the use of smaller speedy, agile, and maneuverable surface platforms and stealth submarines was the choice of the weak—a last resort option for those that were financially or organizationally incapable of investing in the battleship.¹³⁷ However, one needs to be reminded that torpedo boats were very effective against battleships during WWI while the submarine became the battleship’s nemesis during both World Wars.¹³⁸ The battleship never lost its appeal to world navies (before the ascent of the carrier), to be clear. Nevertheless, one could argue, that towards the end of its reign, it was prestige and status concerns that pushed states to build Mahanian battlefleets rather than the battleship’s contribution to the state’s strategic or political objectives.¹³⁹ Put differently, symmetric competition through emulation of the dominant power’s weapon systems and military practices can be inextricably linked to status and prestige rather than the production of actual military effectiveness in the theater of operations. If one thinks of this binary (asymmetry–symmetry) through this lens, then asymmetry can be a valid choice even for a powerful competitor depending on their political objectives or traditional ways of war that might emphasize and prioritize cost imposition over the general destruction of the enemy’s armed forces. In a nutshell, asymmetry could be a fitting strategy for any military organization regardless of financial, technological, or organizational prowess exactly because it promises impactful results through low-cost means; a cost-effective strategy that any actor can find of interest in exploring.

I call this type of asymmetrical competition in the military domain “countervention” which refers to the employment of methods to counter and/or offset the established power’s strategic advantages in the military domain. Countervention consists of three types:

135 Robert M. Cassidy, *Counterinsurgency and the Global War on Terror: Military Culture and Irregular War* (Stanford, CA: Stanford University Press, 2008); John A. Nagl and Peter J. Schoomaker, *Learning to Eat Soup with a Knife: Counterinsurgency Lessons from Malaya and Vietnam*; Eugene Miakinkov, “The Agency of Force in Asymmetrical Warfare and Counterinsurgency: The Case of Chechnya,” *Journal of Strategic Studies* 34, no. 5 (October 1, 2011), pp. 647–80; Austin Long, *The Soul of Armies: Counterinsurgency Doctrine and Military Culture in the US and UK*, illustrated edition (Ithaca, NY: Cornell University Press, 2016).

136 P. W. Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, Reprint edition (New York, NY: Penguin Books, 2009).

137 Jon Sumida, “New Insights from Old Books: The Case of Alfred Thayer Mahan,” *Naval War College Review* 54, no. 3 (2001), pp. 100–111.

138 Brian R. Sullivan, “Italian Naval Power and the Washington Disarmament Conference of 1921–22,” *Diplomacy & Statecraft* 4, no. 3 (November 1, 1993), pp. 220–48. Norman Friedman, *Naval Weapons of World War One* (Barnsley: Seaforth Publishing, 2011).

139 Lilach Gilady, *The Price of Prestige: Conspicuous Consumption in International Relations*, 1st edition (Chicago, IL: University of Chicago Press, 2018).

- I. Countermeasures: the emphasis here is on component-centered countering strategies at the tactical level that seek to deny the strategic advantage conferred by critical weapons systems in the established power's arsenal. Some examples could encompass the development of decoys against missile defense systems, the deployment of the DF-26D ASBM, or the Japanese O93 torpedo, the so-called Long Lance.¹⁴⁰
- II. Counteroperations: Architectural/operational novel thinking that seeks to cancel the established power's strategic advantages at the operational level of strategy through the unexpected composition or integration of existing or older technologies within the same concept of operations. An illustrative example is China's Anti Access/Area Denial that has capitalized on old technologies such as ballistic missiles, diesel electric submarines, or mines as a cost-imposing strategy to U.S. power projection capabilities or carrier warfare.¹⁴¹ Another example would be China's experimentation with swarming and the combination of crewed and uncrewed platforms against the enemy's logistical lines.¹⁴²
- III. Counterstrategies: this subcategory refers to the development of new weapons systems and the creation of a new way of war or theory of victory whose aim is to negate the established power's strategic advantages at the strategic level of war (i.e., the development of the Japanese aircraft carrier warfare against the U.S. battlefleet).¹⁴³

Once a new way of war emerges and a revolution is established, competitors will try to emulate, but we should also expect that they will try to counter it. In fact, this is the dominant pattern in military history: revolution begets counterrevolution. However, how can one predict which option a rising power will choose to prioritize? The German Navy emulated the British Royal Navy through the construction of battleships (symmetric competition), but it also chose to invest heavily in the submarine for sea denial (asymmetric competition).¹⁴⁴ While emulation might take place for reasons that allude to prestige or status-seeking behaviors, asymmetric competition through countering usually is what carries the potential to surprise and challenge the established power in the theater of operations especially at the operational or strategy levels. As a matter of fact, the British detected and understood the intentions behind Germany's Dreadnought program, but they were highly surprised by the use of the submarine as a sea denial weapon since it did not match their own preferences and operational roles assigned to this platform.¹⁴⁵ In any case, the British were taken by surprise

140 Sadao Asada, *From Mahan to Pearl Harbor: The Imperial Japanese Navy and the United States* (Annapolis, MD: Naval Institute Press; Reprint edition, 2013).

141 Stephen Biddle and Ivan Oelrich, "Future Warfare in the Western Pacific: Chinese Antiaccess/Area Denial, U.S. AirSea Battle, and Command of the Commons in East Asia," *International Security* 41, no. 1 (July 2016), pp. 7–48.

142 Emilie Stewart, "Chinese Perspectives on UAVs and Manned/Unmanned Teaming in Future Conflicts," LLNL CGSR lecture (July 23, 2024). <https://cgsr.llnl.gov/event-calendar/2024/2024-07-23>.

143 James H. Belote and William M. Belote, *Titans of the Seas: The Development and Operations of Japanese and American Carrier Task Forces During World War II* (New York, NY: Harper & Row, 1975); David Evans and Mark Peattie, *Kaigun: Strategy, Tactics, and Technology in the Imperial Japanese Navy, 1887-1941* (Annapolis, MD: Naval Institute Press, 2015).

144 Michelle Murray, "Identity, Insecurity, and Great Power Politics: The Tragedy of German Naval Ambition Before the First World War," *Security Studies* 19, no. 4 (2010), pp. 656-688.

145 Williamson R. Murray and Allan R. Millett, *Military Innovation in the Interwar Period* (New York, NY: Cambridge University Press, 1998).

and suffered heavy losses due to the German U-boats.¹⁴⁶ On the other hand, it was the Japanese that conceived carrier-based aviation as an independent counterweapon against the U.S. battlefleet while, paradoxically, the submarine remained a Mahanian platform and it was never conceptualized as a platform for economic warfare.¹⁴⁷ The empirical variation in rising powers' vacillation between emulation and counterintervention needs to be understood and explained through a systematic analysis of the phenomenon.

Given the consequential nature of asymmetric competition in a contest between a rising power and the established power, under what conditions should we expect that a rising power would choose to develop and deploy platforms, operational concepts, or strategies in order to negate and cancel its established competitor's military advantages instead of trying to imitate them? What could be some pointers or parameters that create more incentives for a rising power to prioritize asymmetric competition?

One indicator is related to the established power's preferred way of war and technological enablers and the extent to which dependencies are created by the monopoly of a certain technological revolution.¹⁴⁸ To be fair, all theories of victory and all technologies have weak spots, but some ways of war enabled by certain technologies lead to more dependencies and, therefore, more opportunities for a competitor to exploit their vulnerabilities.¹⁴⁹ Based on the technology that each theory of victory capitalizes on, one could see that some technological eras offer technologies that are more or less penetrable or addressable by asymmetry, creating more or less dependencies that the enemy could take advantage of.¹⁵⁰ In a nutshell, some technologies open themselves up to contestation more than others.

For instance, pre-industrial era theories of victory were simple, created very few dependencies and vulnerabilities for the competitor to seize. As technological progress moved forward at a rapid pace in the 20th century, armies profited from new weapon systems, increasing their military effectiveness exponentially. As Christian Brose explains, "prior to the information revolution, the kill chain was largely concentrated in single military platforms...Platforms collaborated, to be sure, but for the most part, an individual platform had to be its own self-contained kill chain."¹⁵¹ The advent of post-industrial revolution weapons (information age weapons), however, profoundly transformed the conduct of war through the emergence of network centric warfare. The information age, with the proliferation of sensors, super computers, data processing centers and rapid communications,

146 Ibid.

147 Carl Boyd and Akihiko Yoshida, *The Japanese Submarine Force and World War II* (Annapolis, MD: Naval Institute Press, 2012).

148 Jacquelyn Schneider, "The Capability/Vulnerability Paradox and Military Revolutions: Implications for Computing, Cyber, and the Onset of War," *Journal of Strategic Studies* 42, no. 6 (September 19, 2019), pp. 841-863. <https://doi.org/10.1080/01402390.2019.1627209>. Accessed March 30, 2025.

149 Ibid.

150 Julia Macdonald and Jacquelyn Schneider. "Battlefield Responses to New Technologies: View from the Ground on Unmanned Aircraft." *Security Studies*, 28, no. 2 (2019), pp. 216-249. <https://www.tandfonline.com/doi/full/10.1080/09636412.2019.1551565>. Accessed March 30, 2025.

151 Christian Brose, *The Kill Chain: Defending America in the Future of High-Tech Warfare* (New York, NY: Grand Central Publishing, 2020), p. 20.

promised an unparalleled situational awareness at the tactical level for fighters and at the operational level for strategists. Situational awareness meant more precision, and higher precision translated into improved fire effectiveness. All these advancements are thanks to an expanded network of platforms across various military domains that created a decentralized network of battle or, in other words, an overstretched kill chain composed of many nodes that serve different purposes. The militaries that reaped the benefits of the information age saw their military effectiveness increase drastically. The non-use of new technologies for the purpose of the military effort became purely unthinkable. Militaries deleted from their training manuals previous practices and focused on mastering new technologies. Past practices were judged obsolete, fairly, and the new network-centric and precision strike regime dominated strategic thinking.¹⁵²

Another element that increased proportionally to military effectiveness, however, was dependency on sensors, data processing centers, digital communications, and cyber as well as space-enabled operations. The critical nodes of the war effort were highly dispersed, creating a plethora of diverse vulnerabilities a competitor can exploit. Put differently, whereas industrial age platforms and weapons had to be physically destroyed by the enemy through kinetic means in order to prevail, information age warfare has highly depended on very vulnerable enablers that would cost prohibitively high amounts of resources to protect while a competitor can neutralize them using relatively cheap kinetic or non-kinetic means.¹⁵³ In a way of war where C4ISR¹⁵⁴ are at the heart of the military effort, an enemy is highly incentivized to attack those centers and enablers in order to blind the enemy and disrupt their operations even without the actual destruction of its military capabilities. Disruption is a highly promising cost-imposing strategy when over-reliance on high technology is the case even when the actual destruction of the enemy's military forces does not take place, as Clausewitz would have it. In a nutshell, the higher the dependency on specific high-tech platforms or enablers, the more incentives a competitor will have to lean towards the choice of asymmetric competition in order to cancel the established power's strategic advantage.

A second indicator about the prospect of a rising power choosing asymmetric competition through countervention is the opportunity cost compared to that of emulation. If exploiting the dominant power's weaknesses could take place through low-tech/low-cost countermeasures and is judged to be a feasible and viable strategic choice, then the incentives to turn the rules of the game in a cost-effective way are powerful.¹⁵⁵ For instance, during the industrial era, destroying the enemy's logistical lines or factory production lines of war material required heavy investments in bombers for strategic bombing campaigns. Countervention was, in fact, an expensive and laborious business that required a heavy industry for the production of aircraft, a brilliant scientific base, extensive training for pilots, and the development of a new doctrine that detached the aircraft from the army as an auxiliary

152 Thomas G. Mahnken, "Weapons: The Growth & Spread of the Precision-Strike Regime," *Daedalus* 140, no. 3 (July 2011), pp. 45–57.

153 The big vulnerability of industrial era platforms and weapons were logistical lines that were targeted quite extensively during conflicts. See Ryan Baker, *Logistics and Military Power: Tooth, Tail, and Territory in Conventional Military Conflict* (PhD Dissertation, The George Washington University, 2020).

154 *Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance*.

155 J. G. Eaton, "The Beauty of Asymmetry: An Examination of the Context and Practice of Asymmetric and Unconventional Warfare from a Western/Centrist Perspective," *Defence Studies* 2, no. 1 (March 1, 2002), pp. 51–82.

weapon, elevating it to an independent platform and, consequently, an independent service. It was a daunting task from a financial, training, scientific, and organizational point of view.

On the antipode of this, some technologies can be contested through existing military means of older technology or of newer technology that is low cost.¹⁵⁶ For militaries that are highly reliant on high-tech platforms or guided munitions where detection, tracking, and killing take place through the sophisticated coordination and flow of information among sensors, command and control (C2), and the actual platform or munition, a competitor is incentivized to disrupt the flow of information and decapitate the platform or munition instead of physically destroying it.¹⁵⁷ Such an operation can take place through kinetic means against vulnerable nodes of this “system of systems” such as anti-satellite (ASAT) weapons, old ballistic missile technology, or through non-kinetic means such as jamming. For instance, a low-cost 100-watt jammer can blind and confuse a Global Positioning System (GPS) guided munition while the simple deactivation of radars on a state’s surface-to-air missile (SAM) batteries can severely complicate an advanced air force’s suppression of enemy air defenses (SEAD) operations.¹⁵⁸ In fact, while high-tech militaries have steadily moved towards expensive and elaborate platforms as well as weapons systems, competitors have been reminded of older technology systems whose cost is relatively low; a fact that translates into production of higher numbers. While quality has been the motto of Western militaries, as Mike Horowitz recently argued, the mass is about to make a comeback.¹⁵⁹ Signs of such an eventuality were observed decades ago. An indicative example is Ballistic Missile Defense and its perpetual promise to protect the U.S. mainland against nuclear attacks. The technological advances the system has undergone notwithstanding, a competitor can outsmart interceptors through the use of MIRV’ed missiles (a Cold War technology), simple decoys, chaffs, or jamming or by simply deploying bigger number of ballistic missiles.¹⁶⁰ Apart from the technical availability of countermeasures, the cost effectiveness argument against mid-course missile defense is quite compelling. According to Laura Grego, “For a system that requires up to four interceptors per credible object and 10 credible objects per real target, the defense could conceivably need to spend 50–150 times as much as the offense, interceptor to missile, to keep pace.”¹⁶¹

Put differently, the overreliance on high-end, expensive, and deeply elaborate platforms has made their destruction unacceptable, offering an opportunity to a competitor to threaten them through a big number of “attributable” low-cost platforms or munitions.¹⁶² For instance, a swarm attack—not even an artificial intelligence (AI)-enabled one—against a carrier strike group will force destroyers

156 Jacquelyn Schneider, “The Capability/Vulnerability Paradox and Military Revolutions: Implications for Computing, Cyber, and the Onset of War.”

157 Thomas G. Mahnken, “Weapons: The Growth & Spread of the Precision-Strike Regime.”

158 J. G. Eaton, “The Beauty of Asymmetry: An Examination of the Context and Practice of Asymmetric and Unconventional Warfare from a Western/Centrist Perspective,” *Defence Studies* 2, no. 1 (March 1, 2002), pp. 51–82.

159 Michael C. Horowitz, “Battles of Precise Mass,” *Foreign Affairs* (October 22, 2024). <https://www.foreignaffairs.com/world/battles-precise-mass-technology-war-horowitz>. Accessed March 30, 2025.

160 Laura Grego, “Missile Defense and Nuclear Weapons: Charting a Course to Security in The Next Fifty Years of Nuclear Proliferation” in Sharon Squassoni, ed., *Shielded from Oversight: The Disastrous US Approach to Strategic Missile Defense*. (Cambridge, MA: Union of Concerned Scientists, 2021).

161 *Ibid.*, p. 38.

162 Michael C. Horowitz, “Battles of Precise Mass.”

and carrier air defense systems to fire expensive AEGIS-enabled SM-3 missiles against much cheaper drones which means that even if the attack is intercepted, the carrier strike group will have spent millions of dollars in defense, seriously depleting its high-end depository of smart defenses. Right on this point, Iran's recent attack against Israel with a combination of drones, cruise, and ballistic missiles was successfully intercepted by Israel's highly advanced defenses. However, one needs to consider the cost behind such a success; a question that is pressing if one compares the inventory of offensive systems revisionist powers have at their disposal with the defenses that status quo states possess. According to a report, the offensive cost was \$80 million while the defense cost is calculated at around \$1 billion.¹⁶³ The wide gap between emulation of high-end, expensive platforms or weapon systems, on the one hand, and low-tech, inexpensive albeit reliable platforms or munitions, on the other hand, confer upon asymmetric competition an irresistible allure for a rising power that will seek cost-imposing strategies against the established competitor.¹⁶⁴

Finally, a third indicator that is not related to the actual nature of the technology or its countering cost is the competitor's capacity to discern, appreciate, and capitalize on the opportunities offered by the technological environment. As I have already mentioned, organizations perceive and understand their environment through cognitive frames that color some choices in more favorable terms than others. Some militaries have traditionally embraced asymmetry which renders them better candidates for the adoption of such practices while others have traditionally valued symmetry and dominance through destruction instead of disruption. An organization's historical experience and lessons learned are the reasons behind such preferences.¹⁶⁵ To be sure, some military organizations tend to value asymmetrical ways of war because of power asymmetry. However, as time passed and the potential of asymmetry proved itself in the field of operations, asymmetric military practices were institutionalized and elevated to doctrinal guidance which was consolidated through training and organizational standard operating procedures (SOPs).¹⁶⁶ In other words, an organization will detect and experiment with strategies that are compatible with previous practices regardless of differences in power balances or even geography. These practices refer to what "a given group has invented, discovered, or developed in learning to cope with its problems of external adaptation, and that have worked well enough to be considered valid, and, therefore, to be taught to new members as the correct way to think, perceive and feel in relations to these problems."¹⁶⁷ Based on this definition, organizational frames or prisms (previously tested successfully) continue to serve as problem solving mechanisms or uncertainty reduction tools that help organizations inject some order and familiarity in the new environment that is observed in order to make sense of it.¹⁶⁸

163 Ibid.

164 Evan Braden Montgomery, "Competitive Strategies against Continental Powers: The Geopolitics of Sino-Indian-American Relations," *Journal of Strategic Studies* 36, no. 1 (February 1, 2013), pp. 76–100.

165 Austin Long, *The Soul of Armies: Counterinsurgency Doctrine and Military Culture in the US and UK*, Illustrated edition (Ithaca; London: Cornell University Press, 2016).

166 Ibid.

167 Mahnken, *Uncovering Ways of War*, p. 10.

168 Ibid, p.16.

Take for instance, the interwar Japanese Imperial Navy. Its foundational experience at the Tsushima Bay sea battle against the Russian Navy confirmed and venerated asymmetric tactics against the enemy's battlefleet. Even though in 1904 the Japanese navy was a brown water navy experienced in conducting operations close to the coast, its preparations to fight against the U.S. Navy in a blue water environment was drastically impacted by its shared and widely accepted ideas on the effectiveness of hit-and-run operations in the context of an attrition strategy close to the shore.¹⁶⁹ Even though Japan had the benefit of bases in the Pacific that it could use as launching pads for operations against the U.S. Navy, Japan's operational plans completely disregarded this advantage. Instead, Japan's navy chose plans of operations that focused on attrition strikes delivered by stealth, agile, and quick platforms when it is least expected, extrapolating its theory of victory from its previously tested brown water environment into the vast surface of the Pacific. Put differently, the geographical environment changed but ideas on how wars are fought and how victory is gained proved to be more resilient. As far as power balances are concerned, the example of the Italian Navy is a good one. Regia Marina's emphasis on sea lines of communication (SLOC) protection through asymmetric tactics such as hit-and-run operations defined the organization's preferred choices against an adversary of similar naval wherewithal, the French Navy. While Italian strategists invested in battleships, in reality, the core of the fleet and main fighting power was their cruisers and submarines: platforms assessed as the most capable for carrying out hit-and-run operations/sea denial against an enemy of comparable naval power.

In a nutshell, some organizations—thanks to their traditions and lessons learned from historical experiences—are equipped with cognitive frames that set them up nicely for detection of asymmetric opportunities as well as the development of practices and systems that will carry out asymmetric missions. Regardless of the nature of the technological environment and the opportunities it might offer, a military will need to have the intellectual legacy and cognitive tools to translate its material environment into ideas for asymmetric competition through countering. A deep dive into a military's history, milestones, and defining experiences will help an analyst put together an organizational profile that will reflect its tendency for either destruction (symmetric competition) or disruption (asymmetric competition).

Policy Recommendations in Lieu of Conclusion

This chapter has set two things as its objectives: first, I wanted to offer a conceptual framework in order to shed some light upon the concept of "asymmetric competition" between a rising and an established power in pursuit of strategic advantages in the military domain. Second, I asked when we should expect to observe the phenomenon. I offered three indicators: two that pertain to the actual nature of the technological context within which the great power competition takes place and one indicator that is linked to the rising power's set of preferences and values regarding ways of war that render them either positively or negatively pre-inclined towards asymmetry. The closing question that systematic future research should shed light upon is the following: in case all three indicators are present, how do we best detect, track, evaluate, and assess a competitor's asymmetric

¹⁶⁹ Thomas Mahnken, ed., *Competitive Strategies for the 21st Century: Theory, History, and Practice* (Stanford, CA: Stanford Security Studies, 2012).

strategies which are aimed at cancelling an established power strategic advantages while exploiting its vulnerabilities?

Very briefly, I will offer some suggestions regarding both data collection practices as well as analysis. The United States could massively improve its capacity to detect and understand a competitor's asymmetric plans by, firstly, acknowledging cognitive limitations in intelligence analysis in an effort to escape mirror imaging. This challenge can be addressed by multi-disciplinary working groups, inter-agency cooperation, and the use of regional experts that are familiar with the competitor's history as well as sociopolitical and military developments. Second, more work needs to be done in delving into primary resources. Some research organizations that are part of the military as well as some think tanks in Washington, DC have contributed a great deal towards this direction. More needs to be done. U.S. strategists need to familiarize themselves with the PLA's history, major doctrinal (dis)continuities and the drivers behind such events as well as internal debates regarding weapon characteristics, potential operational roles, and alternatives. Most critically, each service's preferred way of war needs to be analyzed with a focus on its theory of victory, critical task, and preferred platforms, as well as emphasized metrics of effectiveness according to which these platforms are assessed, evaluated, or even reconfigured. This suggestion is especially critical with regard to emerging technologies. U.S. analysts need to understand what the PLA considers as its main challenges, the questions it is asking at the tactical and operational levels, and how it is trying to address them. Each military has a different set of challenges toward which thinking as well as resources are channeled accordingly. A first step towards this direction is to understand how the competitor thinks about future war, what they value as critical skills and capabilities to have, what missions are prioritized, and what questions and/or vulnerabilities need to be addressed. All the above mentioned might sound obvious, but the majority of strategic thinking in the United States and Europe has really involved assumptions influenced by the projections of their own experiences and ideas of warfare onto China's views on how future conflict will look like.

Finally, the United States should face its worst nemesis and start thinking in asymmetrical terms in a big break from its past. I have tried to convince the reader that asymmetry as a cost-effective/cost-imposing strategy is not just for the weak; it can also confer benefits to militaries of all sizes. Let me repeat, asymmetric competition as a term should be disassociated from power balances and instead be directly linked to asymmetry of means and the element of surprise above everything. As a matter of fact, the United States had a deep knowledge and advantage in cost-imposing strategies during the Cold War, thanks to Andrew Marshall and his legendary Office of Net Assessments (ONA). Somehow, ONA's legacy faded during the era of uncontested U.S. supremacy, and U.S. strategists need to refresh their knowledge on competitive strategies now more than ever.¹⁷⁰ Within this spirit, the United States has already initiated a shift in its strategic thinking towards embracing quantity and mass of low-tech, "just-good-enough," cheaper, and disposable platforms, as well as munitions. The Air Force has plans to procure cruise missiles at \$150,000, a price much lower than their current cost which varies between \$1 and \$3 million.¹⁷¹ More similar procurement choices will be needed but, more critically,

170 Thomas Mahnken, ed., *Competitive Strategies for the 21st Century: Theory, History, and Practice* (Stanford, CA: Stanford Security Studies, 2012).

171 Michael C. Horowitz, "Battles of Precise Mass."

new thinking is necessary in order to integrate cheaper and more disposable systems along with legacy high-tech platforms within the same concept of operations in a way that future plans will take advantage of the enemy's vulnerabilities while negating its strategic advantages. In a future theater of operations where the U.S. strategic advantages (command of the commons, free movement of navigation, situational awareness and precision, C4 connectivity, and rapid flow of information) will be contested, the U.S. will need to defend them or learn how to sacrifice some of them in a way that will sustain operations for as long as it will be needed. As Jacquelyn Schneider and Julia McDonald have pointed out very aptly, the U.S. military needs to learn new ways to "gracefully degrade by gradually losing effectiveness instead of failing catastrophically."¹⁷²

Most critically, the United States will have to play the same asymmetric "game" in order to cancel the enemy's strategic advantage through cost-effective solutions combining the element of surprise to that of creativity in order to seize the initiative. The recent PLA reforms have demonstrated a number of vulnerabilities in China's military organizational structure. For instance, the United States can take advantage of China's centralized command and the Chinese Communist Party (CCP)'s obsession over its control of the military. This has led to a number of paradoxical organizational choices. As an example, China's Central Military Committee (CMC) remains in control of People Liberation Army Rocket Force's (PLARF) missile brigades dispersed in regional theaters of operations, leaving no space for initiative by local commanders. Communications and coordination between PLARF theater commanders and CMC decisionmakers during a crisis are a weak spot of China's strategy that the United States could capitalize on. To make things even more appealing for U.S. disruption operations, PLARF, although in control of China's conventional and nuclear missiles, is dependent on PLA's Strategic Support Force (PLASSF) for highly critical enabling services such as target acquisition or even missile guidance.¹⁷³ For the perfectly coordinated execution of missions, flawless jointness between PLARF and PLASSF is necessary, which, nevertheless, takes either practical experience in real operational environments or military training and exercises under conditions that approach realistic scenarios.¹⁷⁴ China will have to work very hard to make up for its lack of real war experience. It will have to work even harder in order to offset its vulnerabilities due to its preference for a centralized command that, in reality, disempowers certain services in favor of tighter control of CMC over military operations. The United States will have to target these indicatively mentioned weak spots through several ways such as cyber operations or disinformation campaigns. In the sea domain, emphasis will need to be given to stealth platforms for sea denial operations, a big break from the Navy's Mahanian character and emphasis on sea control as it was enabled by carrier strike groups in the past. For this to happen, the "reign" of destruction needs to come to an end, offering its place to the era of disruption and appreciating it as an equally powerful way of war in the current technological environment.

172 Jacquelyn Schneider and Julia Macdonald, "The Information Technology Counter-Revolution: Cheap, Disposable, and Decentralized," *War on the Rocks* (July 19, 2021). <https://warontherocks.com/2021/07/the-information-technology-counter-revolution-cheap-disposable-and-decentralized/>. Accessed March 30, 2025.

173 David Bickers, "Understanding the Vulnerabilities in China's New Joint Force," *Joint Force Quarterly* 103 (4th Quarter 2021). https://ndupress.ndu.edu/Portals/68/Documents/jfq/jfq-103/jfq-103_78-86_Bickers.pdf?ver=UOaRRhfwJQIOBEyr4mzuZg%3d%3d. Accessed March 30, 2025.

174 Lack of realistic conditions for military exercises is a widely observed phenomenon in authoritarian regimes for reasons that pertain to regime insecurity and survival tactics. See Caitlin Talmadge, *The Dictator's Army: Battlefield Effectiveness in Authoritarian Regimes* (Ithaca, NY: Cornell University Press, 2015).

Innovating Around Export Controls Under Technology Competition: The Case of China and Advanced Semiconductors

Caroline Wesson

Technology and innovation have always played an important role in national security. Having access to the most advanced technologies is essential for effective deterrence, economic growth, and maintaining competitive military capabilities. There are also important economic benefits to technological leadership. A country which leads in critical technologies can obtain a strategic advantage over peer-competitors. This reality has led great powers like the United States and China into a technology competition with technological strategic advantage as the prize. Countries must continuously innovate and control access to their advanced technologies to obtain and maintain a strategic advantage. This paper investigates the current landscape of technology competition between the United States and China in advanced semiconductors, a technology that is an important component of many other technologies—both civilian and military—and essential for artificial intelligence (AI). Currently, U.S. companies lead in the design of advanced semiconductor technologies and the United States has therefore applied export controls to limit China's access to this critical technology. China has responded by introducing a suite of policies to “innovate around” U.S. export controls and thus both obtain U.S. advanced semiconductors in the immediate term and develop their own capacity to produce advanced chips in the long term.

This paper outlines China's strategies to innovate around U.S. export control policies on advanced semiconductors. Gaining awareness of China's “innovate around” strategy is the first step for policymakers to safeguard U.S. leadership in advanced semiconductors. There are five broad pathways China is using to innovate around export controls. These broad pathways include (1) technology smuggling, (2) domestic technology and innovation policy, (3) financing programs and regulation, (4) intensifying international linkages in research and development and business connections, and (5) intellectual and talent development programs. The existence of these pathways does not mean export controls are not useful. Controls still have their purpose and are effective in limiting access to important technologies—especially in the short term. In the current technology competition environment, buying *any* time is better than no time at all, especially given the sophistication of adversaries' innovation ecosystems and their access to resources to channel into technology development and technology espionage. Export controls still can deliver an extended *breakout time* for the development of the targeted technology. Additionally, export controls impose costs onto the targeted adversary. These costs include increased spending and resource diversions to build capacity in the targeted technology rather than towards applications of the controlled technology. These costs can further extend the adversary's technology breakout time as well.

The term “innovating around” has been used in the context of business schools and business innovation processes, typically to refer to innovating in ways that complement existing strengths.¹⁷⁵

¹⁷⁵ David C. Robertson, *The Power of Little Ideas: A Low-Risk, High Reward Approach to Innovation* (Boston, MA: Harvard Business Review Press, 2017).

Additionally, those writing within the space of semiconductor competition have identified “innovating out” and “designing around” as strategies through which countries and companies are working through the current export controls applied by the United States onto China.¹⁷⁶ These words have subtle differences from the concept of “innovating around” advanced in this paper. This paper utilizes innovating around to refer to the set of strategies, policies, and actions employed by the People’s Republic of China (PRC) central government and other government entities (such as State-owned Enterprises, or SOEs) to innovate domestically to produce their own advanced semiconductors to rival those of technology leaders in the United States.

While this paper is narrow in focus, it has wider implications for understanding the greater Chinese innovation system. China’s innovate around strategies have been successful in accessing controlled chips, bolstering domestic innovation, and supporting Chinese firms in closing the gap between U.S. and Chinese semiconductor capabilities. The U.S. government must continue to monitor China’s innovation strategies as they connect directly to how the country is pursuing a strategic advantage in advanced semiconductors. This paper is organized as follows: a brief introduction to the current technology competition landscape and its relationship to national security and innovation, an overview of the importance of semiconductors for security and the state of the global semiconductor industry, a list of current U.S. export controls on semiconductors, and a comprehensive list of the policy tools and strategies employed by China to innovate around U.S. controls.

Fostering innovation at home, controlling domestic technology access, and how countries use innovation policies to innovate around

The 2023 U.S. National Defense Science and Technology Strategy articulates that “accelerated technology advancement and innovation are key elements to achieving DOD [Department of Defense] priorities” and to “ensure [U.S.] national security over the long term.”¹⁷⁷ Having superior technologies and setting technological standards can lead to improved performance in warfighting in conflict periods, but also more effective surveillance and deterrence. The United States sees leadership in technology and innovation as a major component of its military advantage.¹⁷⁸ Given this, the U.S. government has an incentive to invest in national innovation through a variety of policy pathways outlined later in this paper, but also to use export controls to impact adversary access to advanced U.S. technologies which are innovated in the U.S. private sector.

Innovations can be both big and small, and often it may not be observable when either a small change in technology or a major innovation has been created which may revolutionize the way in which information is produced, decisions are made, or how wars are fought. Innovation is both an end but also a process. States are concerned with both. When innovation is an end, countries desire to create new technologies that improve their security and economic outcomes. As a process, states seek to consistently foster an environment where meaningful innovations are produced frequently and efficiently. What is the ideal environment for innovation? While every country is different due to

176 William Alan Reinsch, *Designing out U.S. Technology*, Center for Strategic and International Studies (October 15, 2024). <https://www.csis.org/analysis/designing-out-us-technology>. Accessed November 11, 2024.

177 United States Department of Defense, *National Defense Science & Technology Strategy 2023* (June 5, 2024), p. 1. <http://www.cto.mil/wp-content/uploads/2024/05/2023-NDSTS.pdf>. Accessed November 20, 2024.

178 Ibid.

availability of resources, its political system, and culture, an ideal innovation environment reduces barriers to innovation such as high costs, resources, lack of expertise, and a lack of connection between relevant parties who would be employing the innovation.

There are several different ways in which countries can foster innovation. Some pathways leverage heavy government intervention, while others seek to catalyze innovation through networks between government, universities, and businesses or international connections. Countries often create national innovation systems which are sets of policies and strategies which seek to support technological progress and innovation in targeted industries or just in the country's science and technology (S&T) ecosystem generally. There are some additional aspects of national policy that are typically seen as precedents to innovation which include stable governance, regulations and labor standards, and intellectual property protections. Different sets of policies may work better in some national contexts than others but regardless of *how* countries approach innovation, creating an environment that fosters creativity or entrepreneurial risk-taking assists in sustained technological leadership.

In addition to fostering domestic innovation using national innovation systems, states may need to control access to key technologies it produces to prevent an adversary from acquiring advanced technologies and matching the producing country's capabilities. To this end, there is a broad set of policy tools which can be applied to reduce competitors' access to specific technologies. These tools of "economic containment" include "economic warfare," "strategic embargo," and "tactical linkage," each of which involve different levels of disengagement from a competitor.¹⁷⁹ Strategic embargoes are the most common. Meanwhile, export controls are a form of economic containment and seek to "prevent the target state from importing only those items that could make a direct and specific contribution to its military capabilities."¹⁸⁰ Export controls follow a similar, although not equivalent, logic to the policies which surround non-proliferation. The idea is that a country with leadership in a specific technology should seek to extend the time it would take their competitors to break out and begin producing their own rival technologies in the technology space of particular interest.

The modern economy has made effective use of export controls challenging. There are three key characteristics of this change that impact technology competition: (1) there is an increased prevalence of technologies which have both military and civilian uses, (2) there has been a rise in the flow of knowledge throughout the global economic and information systems, and (3) supply chains that produce many technologies are increasingly global and entangled. These new economic realities have opened new doors for countries to work and innovate around export controls. Supply-chain interdependencies have become a major vulnerability for the United States and others. New workarounds and the global flow of information allow countries to develop domestic technological capabilities more quickly, especially when states are effective in creating and implementing innovation policies.

179 Michael Mastanduno, "Strategies of Economic Containment: U.S. Trade Relations with the Soviet Union," *World Politics* 37, no. 4 (1985), pp. 503–31, <https://doi.org/10.2307/2010342> (accessed December 9, 2024); Dong Jung Kim, "Economic containment as a strategy of Great Power competition," *International Affairs* 95, no. 6 (2019), pp. 1423–1441, <https://doi.org/10.1093/ia/iiz201> (accessed December 9, 2024).

180 Mastanduno, "Strategies of Economic Containment: U.S. Trade Relations with the Soviet Union."

Economic Considerations for Innovation

Innovating around is possible in today's economy because of key features including (1) the increased prevalence of dual-use technologies, (2) the rise of the global knowledge economy, and (3) increased entanglement of supply chains. These characteristics have transformed the modern competitive environment, placing innovation at the core of competition.

Increased prevalence of dual-use technologies

Throughout history, technologies have exhibited dual-use characteristics with applications for both civilian and military purposes. The moment today is somewhat unique due to dual-use technologies of today being primarily innovated and advanced by the private sector, with internationalized supply chains and flows of knowledge. While also not necessarily something new, today there are strong civilian-military fusion programs (as exists in China) and instances of technology being applied in manners that violate human rights.¹⁸¹ These matters have turned more attention to civilian technologies that may have military uses of concern. The conversation around dual-use technologies within the current competitive international security environment continues to evolve as technologies mature and governments seek to maintain leadership and navigate relationships with key private technology firms in order to meet such a goal.

Countries must balance between national security, technological innovation, and economic competitiveness on the global market.¹⁸² Getting this mix right is critical because poorly applied export controls can hurt domestic company profits or allow adversaries access to critical technologies. The implication of emerging technologies with dual-use potential is that governments have an incentive to monitor, invest in, and work with private firms in these industries. How these activities take place depends on a country's political system and appetite for industrial policy and regulation. As previously mentioned, the United States has sought to manage this reality through the passage of the Creating Helpful Incentives to Produce Semiconductors (CHIPS) and Science Act, as well as contracts between the military and specific private firms, and through triple-helix, university-industry-government relationships.¹⁸³ China takes a different approach.

Rise of the global knowledge economy

Specialized and advanced knowledge are critical for economic growth, productivity, and advantage within today's global economy. Economic performance is important not only for security, but also for the overall health, survival, and stability of a state. Therefore, states are directly interested in providing an environment for firms to pursue continuous innovation. This means that firms need to lock into systems to access international flows of knowledge and talent. While the benefits of

181 Maria Shagina, "The Role of Export Controls in Managing Emerging Technology," in *The Implications of Emerging Technologies in the Euro-Atlantic Space*, Julia Berghofer, Andrew Futter, Clemens Häusler, Maximilian Hoell, Juraj Nosál, eds. (Cham, Switzerland: Palgrave Macmillan, 2023), pp. 57-72.

182 Scott A. Jones, "Trading Emerging Technologies: Export Controls Meet Reality," *Security and Human Rights* 31, no. 1-4 (2021), pp. 47-59. <https://doi.org/10.1163/18750230-31010004>. Accessed November 18, 2024.

183 Henry Etzkowitz and Loet Leydesdorff, "The Triple Helix – University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development," *European Association for the Study of Science and Technology Review* 14, no. 1 (1995), pp. 14-19. Accessed September 18, 2024.

international science and technology collaborations are many as they inject new knowledge and perspectives into the innovation process, they also have the potential to open a company and its technology to intellectual property theft and exploitation.¹⁸⁴

Increased entanglement of global supply chains

Globalization of production has intensified rapidly since the 1980s, with many industries moving portions of the design and manufacturing process for technologies to two or more countries. Even further, the components needed for manufacturing may be sourced from several different countries, further tangling the number of countries involved in the production of a single technology. In the context of the semiconductor industry, this is seen through the current structure of the industry—with some firms specializing in chip design (fabless firms), those specializing in manufacturing (foundry), and others specialized in support and equipment support to these two types of firms. Globalized supply chains in the industry have opened vulnerabilities for countries to reliably access semiconductors (especially advanced semiconductors) and to control access to advanced technologies.

U.S. and China Competition in Advanced Semiconductors

Advanced semiconductors, such as graphics processing units (GPUs), are the key to powering the most advanced artificial intelligence (AI) systems in both the military and commercial sectors. More advanced semiconductors are better at processing data and applying algorithms to new data for analysis purposes. The most advanced semiconductors are currently only produced by a small number of companies in the United States, Taiwan, South Korea, and Japan. The semiconductor industry has long been dominated by a small number of players, and the industry is unique as supply chains are highly internationalized. Companies typically specialize either in designing semiconductors or manufacturing them—rarely do companies vertically integrate and both design and manufacture. Countries thus worry that even though they may possess a leading design company, they may not be able to reliably access advanced semiconductors due to manufacturing capabilities being in a second country and being performed by a foreign company as well. This is illustrated in Table 1 below.

To create the *most advanced* defense systems and technologies, militaries need access to advanced semiconductors to train algorithms and to apply AI technology. Advanced semiconductors are considered “dual-use goods” because they are found in both “modern warfighting technologies and weapons modeling systems.”¹⁸⁵ Given this, it is important for the United States to both obtain and maintain a steady supply chain of advanced chips, but also to limit access to these chips and the intellectual property (IP) that surrounds their manufacturing as a means of protecting U.S. national security.

Notably, advanced AI chips are also key components for training and operating machine learning and deep learning algorithms, natural language processing, and large language models. These systems

184 Alison K. Hottes, Marjory S. Blumenthal, Jared Mondschein, Matthew Sargent, and Caroline Wesson, *International Basic Research Collaboration at the U.S. Department of Defense: An Overview*. (2023) https://www.rand.org/pubs/research_reports/RRA1579-1.html. Accessed December 9, 2024.

185 Matthew Schleich, “Securing Semiconductors: How to Scale-up Global Semiconductor Production and Protect U.S. National Security at the Same Time,” U.S. Department of State DIPnote (May 15, 2023). <https://2021-2025.state.gov/securing-semiconductors-how-to-scale-up-global-semiconductor-production-and-protect-u-s-national-security-at-the-same-time/>. Accessed November 10, 2024.

have become particularly important and noteworthy following the release of systems such as ChatGPT or Gemini. These systems require many advanced AI chips to operate as well as energy, so much so that these companies have begun to investigate energy solutions for long-term operation. This was challenged though with the release of Chinese-owned Deepseek AI chatbot, which reportedly used significantly fewer AI chips for training, and requires less energy than competitors to produce a comparable quality of algorithm output.¹⁸⁶ This has been called into question though, as the company may have trained portions of the algorithm on other chips and using cloud service providers, obscuring the reality of the total number of chips and cost of training and operating the chatbot service.¹⁸⁷ Regardless, Chinese firms have shown they are serious competitors in AI—illuminating the need to be aware of the Chinese innovation ecosystem supporting advanced semiconductor development.

The Unique Structure of the Global Semiconductor Industry

The supply chain for advanced semiconductors is very global, due to the structure of the industry. Understanding the industry's characteristics illuminates vulnerabilities for accessing chips and the areas in which different countries have design and production advantages. The semiconductor industry is made up of fabless firms and foundry firms, with a small number of firms that perform both functions. A fabless semiconductor firm is one which only designs semiconductor chips, whereas a foundry firm is one which does not design semiconductor chips and instead only manufactures chips. Foundry firms enter contracts with fabless firms where they will take the company's designs and produce the final chips for export. In many cases, foundry firms are in countries with exceptional expertise in manufacturing, and these firms are well known for their rapid innovation in manufacturing processes rather than in design innovation. This type of industry allows for specialization and benefits from the efficiency of dividing labor based upon the skills and resources of varying labor forces around the world. This is desirable for companies but obviously produces vulnerabilities for governments that seek to maintain reliable access to semiconductor technologies.

186 Mary Whitfill Roeloffs, "What Is DeepSeek? New Chinese AI Startup Rivals OpenAI—And Claims It's Far Cheaper," *Forbes* (January 27, 2025). <https://www.forbes.com/sites/maryroeloffs/2025/01/27/what-is-deepseek-new-chinese-ai-startup-rivals-openai-and-claims-its-far-cheaper/>. Accessed February 1, 2025.

187 Charles Mok, "Taking Stock of the DeepSeek Shock," *Stanford Cyber Policy Center* (February 5, 2025), <https://cyber.fsi.stanford.edu/publication/taking-stock-deepseek-shock> (accessed February 6, 2025); Lennart Heim, "The Rise of DeepSeek: What the Headlines Miss," *RAND Commentary* (January 8, 2025), <https://www.rand.org/pubs/commentary/2025/01/the-rise-of-deepseek-what-the-headlines-miss.html> (accessed February 6, 2025).

Table 1: Top Semiconductor Firms, Their Capabilities, and Country of Origin

(Rank based on market capitalization in billion U.S. dollars)

Source: Statista (accessed on 11/18/2024) <https://www.statista.com/statistics/283359/top-20-semiconductor-companies/>

Firm	Capabilities	Country of Origin
Nvidia Corporation (\$3,600)	Fabless	United States
Taiwan Semiconductor Manufacturing Company Ltd. (TSMC) (\$977.57)	Foundry	Taiwan
Broadcom Incorporated (\$795.77)	Fabless	United States
ASML (\$272.47)	Equipment Manufacturer	Netherlands
Samsung (\$256.15)	Both	South Korea
AMD (Advanced Micro Devices) (\$225.31)	Fabless	United States
Texas Instruments (\$187.91)	Both	United States
Qualcomm (\$182.17)	Fabless	United States
Applied Materials (\$153.33)	Industry Services and Equipment Manufacturer	United States
Arm Holdings (\$143.3)	Fabless	United Kingdom
Micron Technology (\$109.96)	Both	United States
Intel (\$107.95)	Both*	United States
Analog Devices (\$105.37)	Both*	United States
Lam Research (\$96.23)	Industry Services and Equipment Manufacturer	United States
SK Hynix (\$87.97)	Both	South Korea
KLA Corp. (\$86.27)	Industry Services and Equipment Manufacturer	United States
Synopsys (\$84.22)	Industry Services and Equipment Manufacturer	United States
Marvell Technology Group (\$78.56)	Fabless	United States
Tokyo Electron (\$66.19)	Industry Services and Equipment Manufacturer	Japan
MediaTek (\$62.39)	Fabless	Taiwan

**Intel Foundry is a different company but was initially a part of Intel as a whole.*

**Analog Devices also partners with foundry firms abroad.*

Many of the top 10 semiconductor firms are located within the United States., but it is important to note that only four of these firms manufacture their own semiconductor chips in the United States. Meanwhile, fabless firms such as NVIDIA, Broadcom, and AMD rely on foundry firms, which are typically located overseas. The U.S. government has acknowledged this supply chain vulnerability, which was a primary motivator for the passage of the 2022 CHIPS and Science Act. The overarching goals of the CHIPS Act are to increase the production of “American-made semiconductors, tackle supply chain vulnerabilities to make more goods in America, revitalize America’s scientific research

and technological leadership, and strengthen American’s economic and national security at home and abroad.”¹⁸⁸ The policy emphasizes the development and strengthening of U.S. manufacturing capabilities in semiconductors through investment programs in semiconductor firms and research, partnerships between companies and universities, collaborations between firms, and the creation of innovation and production clusters around the United States.

Notably, Chinese firms are absent from the above table. Many Chinese semiconductor firms are still growing in their abilities to design and produce semiconductor chips at scale, and much of their current semiconductors being produced are generations behind advanced models, these chips are referred to as legacy semiconductors.¹⁸⁹ Table 2 shows the leaders in semiconductor production in China by market capitalization in 2024. One company of note that is not listed is HiSilicon. While it does not feature in the ranking below, it is a subsidiary of Huawei and has been heavily involved in government initiatives for wholly domestically designed and produced advanced semiconductors. HiSilicon has also made some newsworthy headlines with the design of chips that some argue can compete with advanced NVIDIA chips.¹⁹⁰ Other companies focused on advanced semiconductors in China also include Cambricon, Shanghai Enflame, and Shanghai Biren, but their revenues do not yet compete with legacy chip producers to rank in the table below.

Table 2: Leading Semiconductor Firms in the People’s Republic of China
(Rank based on market capitalization in billion U.S. dollars)

Source: Statista - <https://www.statista.com/statistics/1458131/china-market-cap-of-leading-semiconductor-companies/>, accessed on 11/23/2024

Firm	Capabilities	State-owned?
Semiconductor Manufacturing International Corporation (SMIC) (\$29.2)	Foundry	Yes
Will Semiconductor Co. Ltd. (\$16.91)	Fabless	No
Maxscend Microelectronics Company Ltd (\$9.7)	Fabless	No
Sanan Optoelectronics Co. Ltd. (\$9.55)	Both	No
Montage Technology Co. Ltd. (\$9.12)	Fabless	Yes
China Resources Microelectronics Ltd. (\$8.13)	Foundry	Yes
GigaDevice Semiconductor (\$8.01)	Fabless	No
JCET Group Co. Ltd. (\$6.99)	Industry Services and Equipment Manufacturer	No

188 Democratic Committee on Science, Space, and Technology, “Ensuring the U.S. is Equipped to Lead in Science and Innovation.” <https://democrats-science.house.gov/chipsandscienceact>. Accessed November 11, 2024.

189 Sujai Shivakumar, Charles Wessner, and Thomas Howell, “Balancing the Ledger: Export Controls on U.S. Chip Technology to China,” Center for Security and International Studies (February 21, 2024). <https://www.csis.org/analysis/balancing-ledger-export-controls-us-chip-technology-china>. Accessed November 20, 2024.

190 Timothy Prickett Morgan, “Huawei’s HiSilicon Can Compete with NVIDIA GPUs in China,” The Next Platform (August 13, 2024). <https://www.nextplatform.com/2024/08/13/huaweis-hisilicon-can-compete-with-nvidia-gpus-in-china/> Accessed November 11, 2024.

Hua Hong Semiconductor Ltd. (\$5.71)	Foundry	Partially
Silergy Corp. (\$5.49)*	Fabless	No

*Silergy Corp is “multinational owned” with offices in the United States as well as Taiwan.

Like the rest of the Chinese economy, the presence and dominance of state-owned firms cannot be understated. State-owned firms are often characterized as inefficient and slow to innovate and move, but this is not always the case. These state-owned firms have access to state financing and other resources that non-state-owned firms do not have access to without additional applications for funding. The non-state-owned firms on the other hand are likely not free of Chinese state influence, due to state involvement in the provision of loans, grants and subsidies, research funding, and considerations of civil-military fusion within the industry, but they may have more freedom to take risks and pursue their own business directions.

Given the limited producers of advanced semiconductors in China, there is an opportunity for the United States and its allies to limit access to advanced chips by targeted export controls or other policy innovations to control access and make it more challenging for China to innovate around controls. Concerns about advanced chip access have also intensified as reporting has surfaced that U.S.-designed NVIDIA AI chips have been found in use in Chinese military bodies—specifically state-run AI research institutes and universities.¹⁹¹ Additionally, in January 2025 it was revealed that China’s Deepseek AI models operate on a small cluster of Nvidia AI semiconductors, raising concerns once again about access to advanced U.S. chips in China.

From the U.S. perspective, these developments are concerning and maintaining leadership in advanced semiconductor design and production is critical. China currently has limited *advanced* semiconductor design and manufacturing capabilities. Despite this, it cannot be understated that Chinese design and manufacturing capabilities have rapidly improved since the 2010s and Chinese firms are now able to produce 7 nanometer (nm) chips.¹⁹² The current state-of-the-art advanced semiconductors are 3 nm, for reference of the gap between 7 nm and advanced semiconductors produced by companies such as NVIDIA. China has “stressed the importance of building an indigenous and self-sufficient semiconductor ecosystem ... as critical to national security and military capabilities.”¹⁹³ The Chinese government has mobilized resources and innovated new policies to innovate around U.S. and allied efforts to cut China from accessing advanced semiconductor technology and know-how.

U.S. Export Controls

Before discussing pathways for the PRC to innovate around U.S. export controls, a brief overview of the current U.S. export control regime is necessary. The United States has a history of employing

191 Eduardo Baptista, “China’s Military and Government Acquire Nvidia Chips Despite US ban,” Reuters (January 15, 2024). <https://www.reuters.com/technology/chinas-military-government-acquire-nvidia-chips-despite-us-ban-2024-01-14/>. Accessed November 11, 2024.

192 Vishakha Saxena, “Huawei’s China-Made 7nm Chip ‘Years Behind US,’ Raimondo Says,” *Asia Financial* (April 22, 2024). <https://www.asiafinancial.com/huaweis-china-made-7nm-chip-years-behind-us-raimondo-says>. Accessed December 9, 2024.

193 Bureau of Industry and Security, “Commerce Strengthens Export Controls to Restrict China’s Capability to Produce Advanced Semiconductors for Military Applications,” Office of Congressional and Public Affairs (December 2, 2024). <https://www.bis.gov/press-release/commerce-strengthens-export-controls-restrict-chinas-capability-produce-advanced>. Accessed December 9, 2024.

export controls on critical technologies to major competitors since the passage of the Export Administration Act (EAA) of 1979.¹⁹⁴ However, it is important to note that before this, the United States had engaged in a variety of “strategies of economic containment” which are attempts “to contain the expansion of an adversary’s military power by using economic rather than (or in addition to) political and military means.”¹⁹⁵ Many of these measures, including export controls, were employed with the Soviet Union as the target to maintain technological and economic leadership.

It is critical to note that the effectiveness of export controls hinges on multilateral efforts involving U.S. allies and partners. Without the cooperation of partners and allies, adversaries targeted with export controls can import the desired technology through a third-party country or import a similar technology from a firm located in a partner or ally country. This situation is complicated, as technologies are designed and produced by private companies who are motivated by profit. Without controls, companies will simply fill demand gaps left by U.S. firms who are limited by export controls.

During the Cold War, the United States and its allies worked together to restrict Soviet Union access to advanced technologies. This was done through the Coordinating Committee for Multilateral Export Controls (CoCom) until 1994, at which point a replacement institution was created, the Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies.¹⁹⁶ These large multilateral efforts were challenging at times as countries feared that controlling exports of leading technologies would hurt them economically. Yet cooperation did proceed and in the 1980s, CoCom expanded controls to include a much wider range of technologies such as software, robotics, micro-computers, and computerized telecommunications equipment.¹⁹⁷ There was a growing consensus among Western nations that technologies with civilian designs and applications had the potential for military application. Current U.S. export control policy follows from the Export Control Reform Act (2018), which is expanded upon in Table 3 below. The Export Control Reform Act and consequent expansions of controls by the Bureau of Industry and Security have tightened export controls on key dual-use technologies and have had successes in limiting adversarial access to key U.S. technologies, including advanced semiconductors. It is important to note, though, that these changes and tightening in policies have been met with some criticism from industry stakeholders seeking to maximize profit and reinvest into research and development (R&D) to remain competitive.

Below in Table 3 are the current export controls and innovation policies in place in the United States seeking to limit adversary access to advanced semiconductors and to bolster U.S. innovation and technical advantage in the industry.

194 Craig K. Elwell, “Export Controls: Analysis of Economic Costs,” Congressional Research Service, RL30430 (February 10, 2000). Accessed November 11, 2024.

195 Michael Mastanduno, “Strategies of Economic Containment: U.S. Trade Relations with the Soviet Union,” *World Politics* 37, no. 4 (1985), pp. 503–31. <https://doi.org/10.2307/2010342>. Accessed December 9, 2024.

196 Richard T. Cupitt and Suzette R. Grillo, “COCOM Is Dead, Long Live COCOM: Persistence and Change in Multilateral Security Institutions,” *British Journal of Political Science* 27, no. 3 (1997), pp. 361–389. Accessed December 9, 2024.

197 Michael Mastanduno, “Strategies of Economic Containment: U.S. Trade Relations with the Soviet Union,” *World Politics* 37, no. 4 (1985), pp. 503–31. <https://doi.org/10.2307/2010342>. Accessed December 9, 2024.

Table 3: Existing U.S. Export Controls and Technology Policies for the Semiconductor Industry

Regulatory Trade Policies		
Type	Mechanism	Formal Policy
Export Controls	A form of strategic embargo which denies the country (to which the control is applied) the ability to import the technology specified. ¹⁹⁸ In this case there are groups of policymakers and analysts which monitor the science and technologies being produced in critical industries and technology spaces and determine if that science or technology can be exported by private firms or if it must be controlled due to military and security concerns.	<ul style="list-style-type: none"> • Export Control Reform Act (ECRA) (2018) – established a new process for identifying emerging critical technologies. The Bureau of Industry and Security (BIS) is the primary institution overseeing export controls in this space.¹⁹⁹ • Foreign Direct Product Rule (FDPR)– while there are different specifics of these rules, they articulate controls of products which are produced using goods that are made in the U.S. (such as chips made using U.S. chip manufacturing equipment and software).
Entity List	Regulates and restricts the export of U.S. goods and services which are deemed dual-use or sensitive to specific entities (organizations or individuals) that the U.S. government has identified as security risks.	<ul style="list-style-type: none"> • Entity List managed by the Bureau of Industry and Security (BIS).

198 Ibid.

199 Scott A. Jones, “Trading Emerging Technologies: Export Controls Meet Reality,” *Security and Human Rights* 31, no. 1-4 (2021), pp. 47-59. <https://doi.org/10.1163/18750230-31010004>. Accessed November 18, 2024.

Multilateral Institutions and Agreements		
<p>Multilateral Arrangements</p>	<p>Arrangements and institutions which are comprised of the U.S. and allies/ partners that agree on sets of export controls on specific technologies of interest. These institutions are agreements are of particular importance given the global economy’s structure and the many opportunities for countries to export chips through third countries and avoid controls. Additionally, if substitutable advanced technology from the U.S. is produced in another country that technology would need to also be controlled to ensure that the adversary country cannot access the advanced technology elsewhere and that U.S. companies are not forgoing profits for controls which are not going to be effective due to alternatives available on the market.</p>	<ul style="list-style-type: none"> • Wassenaar Arrangement on Export Controls for Conventional Arms and Dual-Use Goods and Technologies. • Trilateral agreement among the Netherlands, Japan, and the U.S. (later expanded to also include South Korea) that sought to just coordinate controls among all four parties.²⁰⁰
Innovation Policies		
<p>Federal level funding</p>	<p>Provision of subsidies, tax credits, research and design funding, industrial cluster support, and startup support to U.S. firms and semiconductor manufacturers to operate chip manufacturing plants within the U.S. These policies also seek to bolster innovation and build out the necessary human and physical infrastructures needed to maintain competitiveness within the industry.</p>	<ul style="list-style-type: none"> • CHIPS and Science Act • CHIPS Fund • National Advanced Packaging Manufacturing Program • National Semiconductor Technology Center

200 Paul Triolo, “The Evolution of China’s Semiconductor Industry under U.S. Export Controls,” *American Affairs Journal* (November 20, 2024). <https://americanaffairsjournal.org/2024/11/the-evolution-of-chinas-semiconductor-industry-under-u-s-export-controls/>. Accessed December 7, 2024.

Federal workforce development	Programs which support STEM education and training around the U.S.	<ul style="list-style-type: none"> • CHIPS and Science Act – Department of Commerce → create workforce development programs • Reporting has found that 33 CHIPS and Science Act programs are related to “education, training and outreach.”²⁰¹
International cooperation	Encouragement for international cooperation in research and supply chains with allies and partners to create resilience and less reliance on rival countries.	<ul style="list-style-type: none"> • CHIPS and Science Act • S&T agreements and Memoranda of Understanding (MOUs)

It is important to note that the Chinese government has also employed export controls targeting the U.S. semiconductor industry. These controls are motivated primarily to protect domestic industry, encouraging Chinese firms to innovate and work towards advanced semiconductor capabilities, and to hurt U.S. firms seeking to sell permitted chips in the large Chinese domestic market. Chinese export controls are coordinated through the Ministry of Commerce (MOFCOM), the Chinese Customs Bureau, the State Council, and the Central Military Commission.²⁰² These export controls include restrictions on the export of rare earth minerals, specifically gallium, graphite and germanium.²⁰³ The full strategies employed by China to innovate around U.S. export controls on advanced semiconductors and to bolster their own ability to compete in this space will be detailed in the “pathways” section of this paper.

Innovating Around: China’s Pathways

As export control measures have intensified and other countries have agreed to cooperate with U.S. export controls, China has desperately sought to innovate around these barriers to technological, military, and economic growth and progress. China has primarily dealt with this new reality of export controls through “developing new structures to provide better support for the domestic semiconductor industry.”²⁰⁴ The broad pathways to innovate around include (1) technology smuggling,

201 Martha Ross and Mark Muro, “How federal, state, and local leaders can leverage the CHIPS and Science Act as a landmark workforce opportunity,” *Brookings* (January 4, 2024). <https://www.brookings.edu/articles/how-federal-state-and-local-leaders-can-leverage-the-chips-and-science-act-as-a-landmark-workforce-opportunity>. Accessed December 10, 2024.

202 Bureau of Industry and Security, U.S. Department of Commerce, “China Export Control Information,” U.S. Department of Commerce. <https://www.bis.doc.gov/index.php/enforcement/oe/220-eco-country-pages/1040-china-export-control-information>. Accessed November 10, 2024.

203 Cullen S. Hendrix, “China’s export controls on critical minerals aren’t starving the United States—at least so far,” Peterson Institute for International Economics (October 31, 2024). <https://www.piie.com/blogs/realtime-economics/2024/chinas-export-controls-critical-minerals-arent-starving-united-states>. Accessed November 19, 2024.

204 Paul Triolo, “The Evolution of China’s Semiconductor Industry under U.S. Export Controls,” *American Affairs Journal* (November 20, 2024). <https://americanaffairsjournal.org/2024/11/the-evolution-of-chinas-semiconductor-industry-under-u-s-export-controls>. Accessed December 7, 2024.

(2) technology and innovation policy, (3) financing programs and financial reforms, (4) intensifying international linkages in science and technology and business connections both formal and informal, and (5) intellectual and research espionage programs.

The first of these pathways is that of technology smuggling. There are credible reports of advanced, export-controlled semiconductors being available for purchase within China and used in state-affiliated research labs. This indicates that China has been able to effectively source advanced semiconductors through a variety of smuggling pathways. These pathways are displayed in the table below. Smuggling alone may not be a sustainable way to access chips long-term, but can help with the short-term supply of these chips for use in immediate applications or for the purpose of reverse engineering.

Table 4: Technology Smuggling

Pathway Type	Mechanism	Formal Policy
Third party purchases and sales	<p>Chinese firms and research institutions have access to advanced semiconductors through smuggling and purchasing by subsidiary companies.</p> <p>Chinese universities and research institutions have access to advanced chips which they have used for research and development purposes.²⁰⁵</p> <p>Smuggling is also occurring through neighboring countries.²⁰⁶</p>	<ul style="list-style-type: none"> • While not openly articulated as a policy or strategy, chip smuggling has been well documented. • Chips have been found available for purchase in underground markets.²⁰⁷ • Smuggling through third party countries. • Smuggling through pathways involving Chinese subsidiary companies.

205 Oxford Analytica, “Chinese chip smuggling presents fresh US challenges,” *Oxford Analytica Expert Briefings* (2024). <https://www.emerald.com/insight/content/doi/10.1108/oxan-db289534/full/html>. Accessed November 9, 2024.

206 Tim Fist, Lennart Helm, and Jordan Schneider, “Chinese Firms Are Evading Chip Controls, Here’s how the Biden administration can enforce the ban.” *Foreign Policy* (June 21, 2023). <https://foreignpolicy.com/2023/06/21/china-united-states-semiconductor-chips-sanctions-evasion/>. Accessed November 14, 2024.

207 Oxford Analytica, “Chinese chip smuggling presents fresh US challenges,” *Oxford Analytica Expert Briefings* (2024). <https://www.emerald.com/insight/content/doi/10.1108/oxan-db289534/full/html>. Accessed November 9, 2024.

Cloud computing	Chinese firms have been able to utilize cloud computing services provided by U.S. companies that run on the processing power of advanced AI chips, thus circumventing export controls. ²⁰⁸	<ul style="list-style-type: none"> • No formal policy. Many firms, including state-linked firms in China have used cloud computing services like Amazon Web Services (AWS) to access the computing power of advanced semiconductors that would otherwise be subject to export controls.²⁰⁹
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National innovation systems, or sets of technology and innovation policies, are being employed by the Chinese government to bolster domestic production and innovation in advanced semiconductors. There are many different types of policies that fall under national innovation systems, but the most popular are subsidies, guiding strategies and goals, and education investments. China has long employed these types of policies and strategies for the purpose of economic development and strategic industrial targeting, yet the country continues to innovate and introduce new policies—especially tailored for critical technologies such as advanced semiconductors.

Table 5: National Innovation Systems (Technology and Innovation Policy)

Pathway Type	Mechanism	Formal Policy
Subsidies	<p>Financial benefits provided directly to firms to assist with a variety of business activities including but not limited to direct payments to firms, tax reductions or credits, price minimums, subsidy payments to consumers for buying domestically, loans, research and development investments, and infrastructure investments.</p> <p>Benefits are tied to a firm performing a specific action or operating within a critical industry (in this case, the advanced semiconductor industry).</p>	<ul style="list-style-type: none"> • China Integrated Circuit Industry Investment Fund • Made in China 2025 subsidies • National Innovation Fund • State Innovation Fund for Technology-Based SMEs • National Key Technology R&D Program • There are also subsidy programs available at the provincial and municipal level

208 Eduardo Baptista, Fanny Potkin, and Karen Freifeld, “Exclusive: Chinese entities turn to Amazon cloud and its rivals to access high-end US chips, AI,” Reuters (August 23, 2024). <https://www.reuters.com/technology/chinese-entities-turn-amazon-cloud-its-rivals-access-high-end-us-chips-ai-2024-08-23/>. Accessed November 11, 2024.

209 Ibid.

Standards setting	Regulatory policies that establish norms, technical specifications, and requirements that help to guide and define how a specific technology or sets of technologies are developed and deployed. Can assist with fostering innovation and improving interoperability.	<ul style="list-style-type: none"> • China National Semiconductor Standards System (CNCSS) • China Electronics Standardization Institute
Education investment	Investments in educational programs at all levels. Focus on semiconductors for higher education and encouraging students to pursue degrees in relevant fields in science and engineering.	<ul style="list-style-type: none"> • Made in China 2025 outlines educational investments with a focus on the development of key technologies, including semiconductors. • Program for Recruitment of Global Experts has investments in education programs and training programs. • Provincial and municipal levels efforts also exist. • Funding for university programs geared towards creating engineers and scientists for the industry. Some universities have specific programs for this including Tsinghua.
Clustering	Initiatives developed by the government to connect firms, academia, research organizations, and government institutions to one another for more efficient flows of information and knowledge and increased collaborations to better mobilize resources to reach industrial goals.	<ul style="list-style-type: none"> • Yangtze River Delta cluster region • Pearl River Delta cluster region • Beijing cluster region (more focused on R&D and design as well as startups)

Guiding strategies and goals	<p>An official government document which articulates the country’s goals, actions — or future actions, related policies, and values towards a particular technology or industry of interest.</p> <p>Helps coordinate bureaucratic efforts and designate point organizations and institutions for increased efficiency and clear understanding of the overarching strategic goals of the central government.</p>	<ul style="list-style-type: none"> • Made in China 2025 • Innovation-Drive Development Strategy • 13th Five-Year Plan Special Plan for International Science, Technology and Innovation Cooperation • National research plans • Guidelines to Promote National Integrated Circuit Industry Development (2014) • 14th Five Year Plan (2021-2025)
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Technology industries require significant financing to afford cutting-edge research and design processes and expensive manufacturing equipment. Entering developed industry markets such as the semiconductor industry requires significant initial funding and sustained long-term funding due to the fast pace of chip innovation cycles. Therefore, there is a need for funders to take on the risks associated with new firms or firms entering new research and development endeavors. The state can also fill this function. China has developed several different funding mechanisms to support new entrants into the semiconductor industry, and to maintain innovation and operation of national champions like SMIC. Table 6 details the different pathways through which China is using funding to ramp up innovation and manufacturing and innovate around U.S. controls with ambitions of producing 5 nm advanced semiconductors in 2025.

Table 6: Financing Programs and Financial Reforms

Pathway Type	Mechanism	Formal Policy
Start-up financing	Special finance and loan programs for start-up and risk heavy firms related to the semiconductor industry. These include grant programs, investment programs, and favorable loan programs.	Innovation Fund for Technology-Based Small and Medium-Size Firms (InnoFund). ²¹⁰

210 Yanbo Wang, Jizhen Li, and Jeffrey L. Furman, “Firm performance and state innovation funding: Evidence from China’s InnoFund program,” *Research Policy* 46 no. 6 (2017), pp. 1142-1161. <https://doi.org/10.1016/j.respol.2017.05.001>. Accessed November 11, 2024.

Investment and loan programs to established non-SOE firms	Programs for non-state-owned enterprises in the semiconductor industry to receive specialized grants and loans attached to specific activities and goals for the semiconductor industry.	<ul style="list-style-type: none"> • Innovation Fund for Technology-Based Small and Medium-Size Firms (InnoFund).²¹¹
Innovation funds	Specialized funding mechanisms with a focus on developing semiconductor capabilities and firms.	<ul style="list-style-type: none"> • Little Giants Program • Science and Technology Innovation Board Market (STAR) • Innovation Fund for Technology-Based Small and Medium-Size Firms (InnoFund).²¹² • China Integrated Circuit Investment Industry Fund – three phases, Big Fund 1, Big Fund 2, and Big Fund 3 (spanning from 2014-2039) and managed by Sino IC Capital.
Funding foreign acquisitions of semiconductor firms	Government coordinated, funded, and directed acquisitions or attempted acquisitions of foreign semiconductor firms. ²¹³	<ul style="list-style-type: none"> • Government tied funds have been used to invest in foreign firms and to bid to acquire foreign firms. No formal policy exists but there are records of these activities.

Continuous innovation requires a steady flow of new knowledge and fast adaptation of knowledge. Given this, it is helpful for companies and organizations involved in research and design to connect to international flows of knowledge. Different research and ideas are developed all around the world and connections between researchers in one area to researchers in another can result in wholly new perspectives and ideas. Additionally, firms that are behind in the innovation process may be able to catch up through knowledge and technology transfers with global leaders. Another major benefit of international collaborations is the prospect of burden and resource sharing with partners.

211 Ibid.

212 Ibid.

213 Karen M. Sutter, “China’s New Semiconductor Policies: Issues for Congress,” Congressional Research Service, R46767 (April 20, 2021). <https://crsreports.congress.gov/product/pdf/R/R46767/2>. Accessed November 8, 2024.

Table 7: International Linkages in S&T and Business Connections

Pathway Type	Mechanism	Formal Policy
Science Diplomacy and Memoranda of Understanding (MOUs)	These efforts are used for both domestic aims and to cultivate relationships with foreign allies and partners. They are formal bilateral science and technology agreements (STAs). “Access to the latest know-how in S&T has become a critical part of China’s priorities in establishing formal” S&T agreements and relationships. ²¹⁴	<ul style="list-style-type: none"> • Educational exchange and training programs • Creation of joint research facilities • Creation of shared databases or simple data sharing programs • Joint funding of research institutions • Resource sharing • Encourage foreign firms to create R&D facilities in China.²¹⁵
International Education and University Partnerships	<p>Encouraging students to pursue international education in key areas of interest to gain insight and knowledge into research of interest in key technology spaces and industries.</p> <p>Encourages cooperation with foreign universities and programs to bring foreign educators to China.</p>	<ul style="list-style-type: none"> • University partnerships between Chinese and foreign universities²¹⁶ • Educational exchange programs
Joint Ventures	China has encouraged firms to pursue joint ventures with others who may have intellectual property or knowledge that will be of assistance in developing domestic capabilities.	<ul style="list-style-type: none"> • Due to market access barriers, there is pressure on U.S. firms to form joint ventures with Chinese firms to access the Chinese market. This also usually requires the transfer of technology and IP.

214 Caroline Wagner and Denis Simon, “China’s use of formal science and technology agreements as a tool of diplomacy,” *Science and Public Policy* 50, no. 4 (2023), pp. 807-817. <https://doi.org/10.1093/scipol/scad022>. Accessed November 30, 2024.

215 Karen M. Sutter, “China’s New Semiconductor Policies: Issues for Congress,” *Congressional Research Service*, R46767 (April 20, 2021). <https://crsreports.congress.gov/product/pdf/R/R46767/2>. Accessed November 8, 2024.

216 Ibid.

Participating in international technology and industry organizations	<p>China has encouraged firms to be involved in international technology and industry organizations. These organizations may be involved in advocating specific regulations, standards, and/or performing research.</p> <p>There are valuable connections and knowledge-sharing opportunities within these organizations that China has recognized.</p>	<ul style="list-style-type: none"> • Example organizations which China has been involved within include O-RAN, RISC-V, and the Open Compute Project.²¹⁷ • Also increased involvement with industry associations in other countries including the U.S.-based Semiconductor Industry Association.²¹⁸
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China’s intellectual property and talent development programs are coordinated sets of policies which seek to attract science and technology experts to work in China, collaborate with Chinese researchers and companies, and/or develop domestic talent demanded by specific industry of interest. These programs target specific individuals with demanded backgrounds and/or existing research of interest. Some of the practices these programs utilize to obtain knowledge or talent are considered research espionage, while others are more straightforward competitive recruitment programs.

217 Karen M. Sutter, “China’s New Semiconductor Policies: Issues for Congress,” Congressional Research Service, R46767 (April 20, 2021). <https://crsreports.congress.gov/product/pdf/R/R46767/2>. Accessed November 8, 2024.

218 Ibid.

Table 8: Intellectual and Talent Development Programs

Pathway Type	Mechanism	Formal Policy
Talent Programs	<p>Talent programs are policy packages which seek to improve the talent pool of skilled researchers, engineers, experts, and professionals to support the development of a specific industry—or for overall economic growth and productivity increases.</p> <p>These programs are concerned with recruiting experts from abroad to work within China and Chinese firms. They may target foreigners but often seek to leverage the Chinese diaspora. These programs also typically include education and workforce development programs.</p>	<ul style="list-style-type: none"> • Thousand Talents Plan or the “Program for Recruitment of Global Experts” – this program is composed of six subprojects with different focuses in terms of career level and industry focus.²¹⁹ • The thousand talents program also pays researchers to present their research in China, use lab space in China, and participate in other activities that transmit research findings and knowledge to individuals, organizations, and firms in China. • China Academy of Sciences’ IC Personnel International Training Center.
IP Laws	<p>Enforcement and protection of intellectual property rights for technologies and knowledge held by U.S. and other foreign firms operating in China has not always been adhered to.</p> <p>In many cases foreign firms seeking to operate within China have been required to transfer technology and transfer specific IP to China based firms.²²⁰</p>	<ul style="list-style-type: none"> • China has required firms operating within the country to license IP to Chinese companies to access the Chinese domestic market. • Joint ventures and formal collaborations have also been required.

In addition to these five broadly defined innovate around approaches Chinese companies can (and have) also pursued software solutions and improved machine learning (ML) techniques to maximize the efficiency of chips that are not protected by U.S. export controls.²²¹ While this is an innovate-around tactic, it is also a practical business decision for firms that seek to continue to

219 Federal Bureau of Investigation, “The China Threat: Chinese Talent Plans Encourage Trade Secret Theft, Economic Espionage,” *FBI: What We Investigate*. <https://www.fbi.gov/investigate/counterintelligence/the-china-threat/chinese-talent-plans>. Accessed January 10, 2025.

220 Karen M. Sutter, “China’s New Semiconductor Policies: Issues for Congress,” Congressional Research Service, R46767 (April 20, 2021). <https://crsreports.congress.gov/product/pdf/R/R46767/2>. Accessed November 8, 2024.

221 Ritwik Gupta, Leah Walker, and Andrew W. Reddie, “Whack-a-Chip: The Futility of Hardware-Centric Export Controls,” *AI Frontiers Initiative, Berkeley Risk and Security Lab* (2024). <https://doi.org/10.48550/arXiv.2411.14425>. Accessed February 4, 2025.

make competitive AI models and applications. These creative software solutions should be carefully considered as they will have important implications for Chinese firms continuing to keep pace with competitors despite restricted access to advanced chips.

Innovating Around: What Does It Mean for the United States?

China has developed several plans, goals, and policies to innovate around U.S. export controls on advanced semiconductors. Their strategies go far beyond smuggling U.S. chips and moving past existing five-year plans and subsidy programs. The level of coordination, policy innovation, and investment in domestic advanced semiconductor development programs is massive and will likely continue to increase as the country accelerates towards 5 nm chip production. These efforts from China do not negate the usefulness of export controls, which are still useful tools—especially as more partners and allies have agreed to apply and enforce U.S. export controls against China. The United States has made smart investments, including those in the CHIPS and Science Act and the Inflation Reduction Act (funded subsidies and tax credits for semiconductor firms). Both acts outline robust investments in R&D in advanced semiconductors and manufacturing processes and support the creation of manufacturing capabilities within the United States. While these programs should assist in countering the advancements in Chinese capabilities in advanced semiconductors, remaining aware of the universe of Chinese innovate-around strategies will be important in continuing to navigate U.S.-China technology competition in advanced semiconductors.

This paper thus offers the following policy considerations for the U.S. to consider to maintain a strategic advantage in advanced semiconductors. Continued innovation and protection of the U.S. scientific enterprise will be important going forward as China continues to adapt how it approaches innovation in this technology area and others.

- *Export controls* – there may be opportunities for innovative approaches to implement controls, public-private partnerships to better understand the timelines for the release of new advanced technologies, and recruitment programs for introducing expertise into BIS to determine appropriate mixes of technology controls and profit opportunities for private firms.
- *Collaboration with allies on export controls* – increased communication with partners and allies to encourage more compliance with U.S. export controls will be essential going forward. The same is true for convincing partners and allies not to allow third-party sales to Chinese (and other adversaries’) firms.
- *Collaboration with allies for knowledge production and manufacturing* – there should be continued efforts to involve allies with manufacturing capabilities to collaborate with U.S. companies in these areas to improve U.S. domestic production of advanced semiconductors and also increase abilities in partner and ally nations with shared national security goals with the United States.
- *Domestic R&D funding* – The United States has always been strong in funding R&D – this should be continued and expanded, especially with a focus on manufacturing processes and sciences, which are not a traditional area for R&D investment.
- *Education programs* – development of education and training programs for students of all educational levels will be critical in staffing manufacturing plants for advanced semiconduc-

tors and continuing to foster a robust R&D environment for future progress in the technology space. These programs should not only include curriculum development, but also the creation of training facilities in partnership with private entities, funding of university laboratories, and scholarship programs.

- *Industrial and innovation clusters* – economic clustering, or the concentration of an industry and supportive industries within a specific geographic location, has been shown to improve innovation outputs and catalyze progress. Investing in clusters focused on semiconductor research and manufacturing will benefit the innovation process and assist in resource mobilization and efficient production going forward. Clusters will require public-private partnerships and the creation of new industry institutions to promote networks for supply chain improvement and knowledge flows.
- *Research enterprise security* – expanding on the concept of export controls, more should be done to investigate cases of research espionage and employee involvement in talent programs abroad. There should be new investigative processes and public-private partnerships introduced to better secure U.S. research, both public and private, in critical technologies.

Technology competition will likely be a feature of the U.S.-China relationship for years to come. Currently, the United States has a strategic advantage in several emerging technologies with national security implications. Maintaining this strategic advantage will be critical. Knowledge of the Chinese strategy to compete in these technologies is an important step for the United States to continue calibrating its approach to export controls and larger national innovation strategies.

Assessing U.S.-Russia Technology Competition

Spenser A. Warren

Russia is engaged in a multifaceted technological competition with the United States. Moscow is pursuing a range of technologies with potentially significant commercial, political, and military implications. Most importantly for American security, Russia is investing in several military-relevant emerging technologies, from hypersonic weapons and space capabilities to artificial intelligence and quantum computing. The sophistication of these technologies varies significantly. For example, Russia fielded a hypersonic glide vehicle before any other country but remains unable to develop a quantum computing device capable of competing with older American and Chinese prototypes despite significant bluster from the Kremlin.

Why is Russia engaging in this competition? How do we gauge whether we are ahead or behind, and by how much? I attempt to answer these two questions in this chapter. I argue that Russia is engaging in technological competition for strategic, status, and commercial means. Moscow sees emerging technologies as necessary for enhancing Russian military power, regaining lost international prestige, and boosting a struggling economy that is overly dependent on hydrocarbons. Certain factors limit Russia's ability to develop critical technologies. Over the past few decades, a significant brain drain has hampered the growth of a highly-skilled, tech-savvy workforce needed for significant technological innovation. While not as significant as some analysts claim, financial constraints have also played some role. Additionally, international sanctions have limited the development of certain emerging technologies, even if they have not been as effective as American and Allied leaders desired.

Furthermore, I argue that we should assess strategic technological competition with Russia by assessing the strategic challenges that Russian technologies pose and our ability to overcome them. Doing so provides a better understanding of the strategic impacts of U.S.-Russia technological competition than simply comparing the level of sophistication of new technologies in each country. I explore Russian hypersonic glide vehicles (HGVs) later in this essay. HGVs are arguably Russia's most significant and strategically relevant technological success in the past decade. Investment in HGVs resulted in the development, production, and deployment of the nuclear-capable Avangard HGV before the United States or other countries could develop similar weapons. However, Russia's hypersonic weapons have had minimal strategic impact and may not ultimately provide the prestige boost that Moscow desires. Russia may have deployed HGVs first, but they are not necessarily "leading" the United States. Rather, I argue that these weapons do not provide a noticeable strategic advantage for Moscow and that the United States may actually gain a decided advantage both in the deployment of its own hypersonic weapons and in the development of defenses to counter Russian hypersonic capabilities, should Washington decide that either are necessary.

I examine the main factors that drive Russia's technological competition with the United States in the next section. These include strategic, status, and commercial interests. The second section discusses the various economic constraints limiting Russia's technological competition. I then provide an overview of Russia's hypersonic weapons. I conclude by assessing who is "ahead" in the U.S.-Russia hypersonic weapons competition.

Sources of Russian Competition

A combination of factors drives Russia's development of particular advanced technologies. While these combinations may be specific to certain technologies, common motifs emerge across Russian technological competition. First and foremost, the development of advanced technologies is tied to Russia's strategic competition with the United States. Advanced technologies are also a hallmark of an advanced and prestigious country, creating status incentives for Russian investment in technologies such as hypersonic weapons or quantum computing. Finally, technology investment provides economic benefits, potentially providing a significant stimulus to a stagnating hydrocarbon-dependent economy.

Strategic Competition

Russian leaders believe that advanced technologies allow Russia to achieve strategic goals in international politics. Technologies can be force multipliers that enhance existing capabilities. They may also allow for the evolution of Russian warfare, allowing Russia to pursue new strategies, conduct stronger non-kinetic operations, and limit the human and financial costs of war. While a range of possible new or improved technologies could enhance Russia's military potential, I focus on four here: hypersonic weapons, artificial intelligence, quantum computing, and space-based weapons.

Hypersonic weapons—especially those that are nuclear capable—bolster Russian nuclear deterrence. Russian leaders worry that the United States may develop a combination of advanced missile defenses and counterforce capabilities that could threaten the survival of Russia's nuclear deterrent and perceive hypersonic weapons as a means to counter this future threat.²²² Russian leaders perceive hypersonic weapons as an effective tool against advanced missile defenses. While one allegedly hypersonic weapon—Kinzhal—has performed poorly against Patriot in Ukraine, Russian leaders expect more advanced systems to be more effective.²²³ Russian professional military writings on nuclear strategy argue that hypersonic weapons are a necessary component of modernization efforts intended to counter missile defense and counterforce threats.²²⁴

Unlike hypersonic weapons, artificial intelligence (AI) is not a purely military technology. However, its military potential is a critical driver of Russian investment in AI. Vladimir Putin has placed a significant emphasis on AI, stating that “Artificial intelligence is the future...for all humankind. It comes with colossal opportunities, but also threats that are difficult to predict. Whoever becomes the leader in this sphere will become the ruler of the world.”²²⁵ Russian leaders perceive AI as a critical

222 Spenser A. Warren, *Security, Prestige, and Power: Understanding the Determinants of Russian Strategic Nuclear Modernization under Vladimir Putin* (PhD dissertation, Indiana University Bloomington, 2023).

223 See Alexander H. Montgomery and Amy J. Nelson, “Ukraine and the Kinzhal: Don’t Believe the Hypersonic Hype,” Brookings Institution (May 23, 2023). <https://www.brookings.edu/articles/ukraine-and-the-kinzhal-dont-believe-the-hypersonic-hype/>. Accessed February 14, 2025.

224 S.V. Karakayev, “The Strategic Missile Forces in Russia Today,” *Military Thought* 29, no. 1 (2020); V.A. Kiselyov, “What Kind of Warfare should the Russian Armed Forces be Prepared for?” *Military Thought* 26, no. 2 (2017), pp. 1-12; V.V. Selivinov and Yu.D. Ilyin, “Methodological Basis for Launching Asymmetric Responses in a Military-Technological Battle with a High-Technology Adversary,” *Military Thought* 28, no. 1 (2019), pp. 20-29; A.Ye. Sterlin, A.A. Protasov, and S.V. Kreidin, “Current Transformations in the Concepts and Power Instrument of Strategic Deterrence,” *Military Thought* 28, no. 3 (2019), pp. 40-51.

225 Russia Today, “‘Whoever Leads in AI will Rule the World’: Putin to Russian Children on Knowledge Day” (September 1, 2017). <https://www.rt.com/news/401731-ai-rule-world-putin/>. Accessed February 14, 2025.

strategic technology, even if they do not perceive it as revolutionary. Russian strategists contend that AI-enabled systems could be used for improving the security of military infrastructure and avoiding accidents at facilities, creating autonomous robotic weapons, collecting and processing a large amount of intelligence, enhancing command and control, predicting adversary actions and reactions, conducting cyberattacks, enhancing information warfare, improving logistics planning, and assisting with weapons development.²²⁶ Russian operations as part of its war against Ukraine have exposed existing weaknesses that threaten Russia's ability to achieve these goals, prompting increased investment and cooperation with Russia's civilian sector to address these issues.²²⁷

Historically, these leaders have seen AI as having the greatest impact on automated warfare and information warfare. Russian strategists have emphasized a shift towards "automated," "roboticized," or "intellectualized" warfare with AI-enabled automated weapons and systems gradually replacing humans on the battlefield.²²⁸ Russia has had greater success with integrating AI into autonomous weapons than developing AI-assisted command and control, reconnaissance, and machine learning-based information processing systems.²²⁹ Russia has made significant progress in the integration of AI into its drones, deploying a drone that uses AI to recognize objects and select targets to strike as part of its full-scale invasion of Ukraine.²³⁰

Moscow has also had some success integrating AI into its information warfare capabilities. AI could have implications for two subsets of Russian information warfare: cyber-psychological and cyber-technical warfare.²³¹ Russian strategists see AI as a useful tool for spreading propaganda, countering adversary information operations, and enhancing the impact of its artificial bots.²³² Uses such as improving deep fakes and proliferating misinformation could confuse an adversary's military, erode citizens' trust in adversary governments, and complicate an enemy's decisionmaking.²³³ AI may also help find and exploit vulnerabilities in an adversary's information technology systems, placing critical infrastructure and systems at greater risk of espionage.²³⁴

226 Anya Fink, "Russian Thinking on the Role of AI in Future Warfare," NATO Defense College (November 8, 2021). <https://www.ndc.nato.int/research/research.php?icode=712>. Accessed February 14, 2025.

227 Samuel Bendett, "The Role of AI in Russia's Confrontation with the West," Center for a New American Security (May 3, 2023). <https://www.cnas.org/publications/reports/the-role-of-ai-in-russias-confrontation-with-the-west>. Accessed February 14, 2025.

228 Anna Nadibaidze, "Russian Perceptions of Military AI, Automation, and Autonomy," Foreign Policy Research Institute (January 27, 2022). <https://www.fpri.org/article/2022/01/russian-perceptions-of-military-ai-automation-and-autonomy/>. Accessed February 14, 2025.

229 Ibid.

230 Will Knight, "Russia's Killer Drone in Ukraine Raises Fears about AI in Warfare," *Wired* (March 17, 2022). <https://www.wired.com/story/ai-drones-russia-ukraine/>. Accessed February 14, 2025.

231 Jeffrey Edmonds et al., "Artificial Intelligence and Autonomy in Russia," Center for Naval Analyses (May 12, 2021), <https://www.cna.org/reports/2021/05/Artificial-Intelligence-and-Autonomy-in-Russia.pdf>; Rod Thornton and Marina Miron, "Towards the 'Third Revolution in Military Affairs: The Russian Military's Use of AI-enabled Cyber Warfare,'" *RUSI Journal* 165, no. 3 (2020), pp. 12-21.

232 V.M. Burenok, "Isskusstvennyy intellect v voennom protivostoyanii budushchevo (Artificial intelligence in the military confrontation of the future)," *Military Thought* 30, no. 2 (2021).

233 Thornton and Miron, "The Russian Military's Use of AI-enabled Cyber Warfare."

234 Ibid.

While automated and information warfare are the primary uses of Russian military AI, Russia has sought to integrate it into other systems for additional purposes. Russia has integrated AI into electronic warfare systems, developing the AI-enabled RB-109A Bylina system that can identify command, control, and communications (C3) targets and uses AI to determine which targets to jam to maximize C3 suppression efforts.²³⁵ Russia also plans to develop AI-assisted guidance systems for several weapons, including Avangard, Kinzhal, the Sarmat intercontinental ballistic missile (ICBM), and the Burevestnik nuclear-powered cruise missile.²³⁶ AI-assisted guidance would complement existing GLONASS²³⁷-based guidance, theoretically ensuring that systems could reach intended targets even if an adversary destroyed or degraded GLONASS satellites.

Quantum technology investment in Russia has two key similarities to Russian AI. First, leaders have tied it to national security. Russia's Quantum Technologies Roadmap in 2019 was part of an effort to promote technological independence and national security, while Vladimir Putin claimed that adversary quantum investment was a serious security threat.²³⁸ Second, quantum is not a purely military technology. Private and non-military state-run corporations are the primary funders of current quantum research in Russia, including Sberbank, the Russian Direct Investment Fund, major telecommunications firms, and Russia's tech companies such as Yandex and VKontakte.²³⁹ But that is the extent of the similarities. While Russia has invested heavily in AI and made significant progress, Russian investment in quantum has been minimal and capabilities remain rudimentary. Russia's Quantum Technologies Roadmap proposed creating a 30-100 qubit computer by 2024 and a 1,000 qubit computer by 2030. However, Russia has only recently unveiled a 16-qubit computer.²⁴⁰ Meanwhile, the largest quantum computers in the United States broke the 1,000 qubit threshold in 2023.²⁴¹

Finally, Russia sees space as an arena of international competition. Russia is competing with the United States for military influence beyond the atmosphere. Among Russia's competitive actions is the development of a potentially nuclear space-based weapon. Such a weapon could pose a threat

235 Margarita Konaev, "Military Applications of Artificial Intelligence: The Russian Approach," In Samuel Bendett et al., "Advanced Military Technology in Russia: Capabilities and Implications," Chatham House (September 2021), pp. 63-74. <https://www.chathamhouse.org/sites/default/files/2021-09/2021-09-23-advanced-military-technology-in-russia-bendett-et-al.pdf>. Accessed February 14, 2025.

236 Edmonds et al., "Artificial Intelligence and Autonomy in Russia."

237 *Globalnaya Navigazionnaya Sputnikovaya Sistema*, or Global Navigation Satellite System.

238 Ekaterina Blinova, "Future Technologies Forum: Russia Races against Time pushing Quantum Computing," Sputnik (July 14, 2023). <https://sputnikglobe.com/20230714/future-technologies-forum-russia-races-against-time-pushing-quantum-computing-1111878551.html> (accessed February 14, 2025); Johnny Kung and Muriam Fancy, "A Quantum Revolution: Report on Global Policies for Quantum Technology," Canadian Institute for Advanced Research (August 2021), <https://cifar.ca/wp-content/uploads/2021/05/QuantumReport-EN-May2021.pdf> (accessed February 14, 2025).

239 Blinova, "Russia Races against Time pushing Quantum Computing."

240 Ibid.

241 Alex Wilkins, "Record-breaking Quantum Computer has more than 1000 qubits," *New Scientist* (October 24, 2023). <https://www.newscientist.com/article/2399246-record-breaking-quantum-computer-has-more-than-1000-qubits/>. Accessed February 14, 2025.

to certain military and commercial satellites.²⁴² Russia may be willing to degrade its own satellites as part of a broad anti-satellite (ASAT) strike, as it is less space-dependent than the United States and expects an American ASAT strike in the early stages of a conflict. Russia's competition in space is also tied to Russian AI and hypersonic investments, as Russia has sought to develop AI-assisted guidance for hypersonic weapons, expecting a war with the United States to reach space and degrade Russia's space-based GLONASS navigation system.

Prestige

Strategic aims—whether defensive or expansionary—are not the sole goal of Russian technological advancements. Prestige plays a significant role in Russia's technology competition with the United States. Status concerns are of secondary importance in most cases, but they may shape decisions that are largely made for strategic gain. For example, strategic concerns are the primary driver of Russian nuclear modernization, but a desire to develop recognizable status symbols played a significant role in Moscow's selection of novel or technologically impressive weapons over others that could have accomplished the same strategic goals.²⁴³ Hypersonic weapons are among the systems that Russia developed to achieve strategic and status goals simultaneously.²⁴⁴

Russia perceives itself as a great power with a unique role in the world.²⁴⁵ Russian leaders also believe that the United States and most European countries do not recognize Russia's rightful status, viewing it as a regional, declining, or former power instead of a great power with global influence. The Kremlin seeks to change Western perceptions of Russia, aiming to earn recognition as a modern, advanced state with an equal stake in global affairs. Restoring this perception of Russian influence is a significant aspect of Vladimir Putin's foreign policy.²⁴⁶ Technology competition plays an integral role in Russia's pursuit of prestige.

Hypersonic weapons are one of several nuclear systems that Russia developed to achieve status aims. Russian nuclear modernization was primarily driven by a perceived future threat from the United States, with Russian leaders worrying that future missile defense and counterforce capabilities would erode Russia's nuclear deterrent. However, multiple systems could have achieved the strategic aims of Russian nuclear modernization, with Russia prioritizing those that could also serve as symbols of advanced status. Two groups of weapons—those that the Kremlin claimed were novel and those that had some claim to a superlative feature such as the fastest bomber or longest-ranged ICBM—were Russia's main focus. Hypersonic weapons were among the novel systems that Russia

242 Spenser A. Warren, "Is Russia looking to put Nukes in Space? Doing so would undermine Global Strategic Stability and ignite an Anti-satellite Arms Race," *The Conversation* (February 17, 2024). <https://theconversation.com/is-russia-looking-to-put-nukes-in-space-doing-so-would-undermine-global-stability-and-ignite-an-anti-satellite-arms-race-223702>. Accessed February 14, 2025.

243 Warren, *Understanding the Determinants of Russian Strategic Nuclear Modernization since 1999*.

244 *Ibid.*, Chapter 7.

245 Rebekah Koffler, *Putin's Playbook: Russia's Secret Plan to Defeat America* (Washington, DC: Regnery Gateway, 2021); Deborah Welch Larson and Alexei Shevchenko, *Quest for Status: Chinese and Russian Foreign Policy* (New Haven, CT: Yale University Press, 2019).

246 Kathryn E. Stoner, *Russia Resurrected: Its Power and Purpose in a New Global Order* (New York: Oxford University Press, 2021); Brian D. Taylor, *The Code of Putinism* (New York: Oxford University Press, 2018).

developed. Vladimir Putin tied these weapons to status on several occasions, highlighting that they had no analogues in the world and that Russia had developed them before the United States or China. For Putin and other senior Russian leaders, these weapons were a recognizable status symbol that showed the sophistication of Russian technology and Russia's defense industry.

AI and quantum are also potential sources of enhanced Russian status. Status concerns play a significant role in Russia's pursuit of AI. As with hypersonic weapons, status is less important than strategic concerns but still a significant factor. Military and commercial AI development is a significant aim of Russian investment in its technology sector, investment that Russian leaders believe is necessary to reduce the status gap between Russia and the United States and to maintain status into the 21st century. Russia's status aspirations also impact its beliefs on the governance of automation and AI, contributing to its opposition to global governance structures.²⁴⁷ Quantum developments may also contribute to status-seeking strategies, with Russia emulating technological powers like China and the United States.

Economic Impacts

Finally, Russia's technology competition has significant implications for Russia's economy. Western analysts frequently underestimate the size of Russia's economy, financial capacity, and defense spending.²⁴⁸ Nevertheless, Russia's economy is struggling. It is heavily dependent on hydrocarbons, making it vulnerable to changes in oil and gas prices and to ongoing shifts away from fossil fuels. Financial sanctions and export controls have also taken a toll on Russia's economy dating to the initial invasion of Ukraine in 2014, even if the economic impacts have not been as significant as Western leaders had hoped. As a result, the Kremlin has looked for various ways to stimulate Russia's economy.

Hypersonic weapons have the fewest economic impacts. However, Russia's defense industries are an important source of economic stimulus, especially in areas where a large part of the Russian workforce is employed in the defense sector. Previous scholarship has found that the economic interests of the defense industry—including the preservation of the workforce of specific firms—played an important role in determining Russian nuclear modernization programs and force structure decisions.²⁴⁹ Similar considerations may have played some role in the development of hypersonic weapons, although recent research has found that the role it played was marginal, at most.²⁵⁰

However, AI and quantum would have significantly larger economic implications. Russian investment in quantum technologies, AI, machine learning, and other advanced computing

247 Anna Nadibaidze, "Great Power Identity in Russia's Position on Autonomous Weapons Systems," *Contemporary Security Policy* 43, no. 3 (2022), pp. 407-443. <https://doi.org/10.1080/13523260.2022.2075665>. Accessed April 9, 2025.

248 Michael Kofman and Richard Connolly, "Why Russian Military Expenditure is much Higher than Commonly Understood (as is China's)," *War on the Rocks* (December 16, 2019). <https://warontherocks.com/2019/12/why-russian-military-expenditure-is-much-higher-than-commonly-understood-as-is-chinas/>. Accessed February 14, 2025.

249 Olga Oliker, *Between Rhetoric and Reality: Explaining the Russian Federation's Nuclear Force Structure* (PhD dissertation, Massachusetts Institute of Technology, 2016), <https://dspace.mit.edu/handle/1721.1/107537> (accessed April 9, 2025); Pavel Podvig, "Russia's Current Nuclear Modernization and Arms Control," *Journal for Peace and Nuclear Disarmament* 1, no. 2 (2018), pp. 256-267, <https://doi.org/10.1080/25751654.2018.1526629> (accessed April 9, 2025); Leah Walker, "Nuclear-Powered Cruise Missiles: Burevestnik and its Implications," *Journal of Science Policy and Governance* 16, no. 1 (2020), https://www.sciencepolicyjournal.org/uploads/5/4/3/4/5434385/walker_jspg_v16.pdf (accessed April 9, 2025).

250 Warren, *Understanding the Determinants of Russian Strategic Nuclear Modernization since 1999*.

technologies is partially driven by a desire to develop an advanced technology sector to spur economic growth, reduce dependence on foreign goods, and provide high-paying, high-tech jobs.²⁵¹ Firms seek to compete with American, European, and East Asian tech companies to gain market share in Russia and abroad and to attract a highly skilled workforce. In AI and quantum, civilian firms such as Sberbank, Yandex, and VKontakte are major investors.²⁵²

Constraining Factors

While Russia is engaging in a significant technological competition with the United States and investing in a range of military and civilian technologies, it continues to lag behind the United States and others in many regards. In AI, Russia ranks 12th in patents and 14th in inventor nationality based on 2019 data.²⁵³ Investment in quantum computing also lags behind Russia's competitors. Several factors may reduce the Russian government's capacity to promote and develop emerging technologies and contribute to these lags. Three are especially important: a crippling brain drain, financial constraints, and export controls.

Russia has experienced a significant brain drain over the past couple of decades. Initially, the prospect of better economic opportunities abroad, especially in the tech sector, drove this brain drain. Several founders and executives of leading technology firms in the United States and Europe are Russian-born and American- or British-educated. Many engineers and designers in American and European technology firms are also Russian. Russia's brain drain has worsened significantly since its full-scale invasion of Ukraine in 2022.²⁵⁴ The exodus of highly skilled labor—either to avoid military service or because of persecuted political views—has created a significant demographic crisis in Russia that is hampering the tech, manufacturing, and financial sectors.

Additionally, Russia faces increasing financial constraints, although Russia's spending priorities have often minimized their impact on military technologies. Russia was already experiencing budget stress in the late 2010s, prompting politically costly pension reforms. The COVID-19 pandemic, declining global gas and oil prices, and the war in Ukraine have exacerbated these issues. Rising oil prices after the height of the pandemic did not benefit the Russian economy as significantly as they did in the 2000s and 2010s, as sanctions placed on Russia limited Moscow's ability to sell on global markets, often relying on intermediaries such as India to purchase oil at below market rates.²⁵⁵

251 Katarzyna Zysk, "Defence Innovation and the 4th Industrial Revolution in Russia," *Journal of Strategic Studies* 44, no. 4 (2021), pp. 543-571. <https://doi.org/10.1080/01402390.2020.1856090>. Accessed April 9, 2025.

252 Blinova, "Russia Races against Time pushing Quantum Computing;" Edmonds et al., "Artificial Intelligence and Autonomy in Russia."

253 UK Government and Intellectual Property Office, *Artificial Intelligence: A Worldwide Overview of AI patents and Patenting by the UK AI sectors* (June 18, 2019), <https://www.gov.uk/government/publications/artificial-intelligence-a-worldwide-overview-of-ai-patents> (accessed February 14, 2025); World Intellectual Property Office, "Technology Trends: Artificial Intelligence" (2019). https://www.wipo.int/tech_trends/en/artificial_intelligence/story.html. Accessed February 14, 2025.

254 Stacey Vanek Smith, "She had a Dream Job. Now, She's Part of a Massive Brain Drain hammering Russia," NPR (May 31, 2023). <https://www.npr.org/2023/05/31/1176769042/russia-economy-brain-drain-oil-prices-flee-ukraine-invasion>. Accessed February 14, 2025.

255 Spenser A. Warren and Sumit Ganguly, "India-Russia relations after Ukraine," *Asian Survey* 62, no. 5-6 (2022), pp. 811-837. <https://doi.org/10.1525/as.2022.1799235>. Accessed April 9, 2025.

Some evidence suggests these constraints may be increasing in severity, as Russia decreased certain payments to wounded servicemembers in November 2024.²⁵⁶

Finally, export controls may serve as a constraint on Russian technology competition. Many advanced technologies require high-end components such as advanced microchips. The United States and several of its European and Asian partners responded to Russia's 2022 invasion of Ukraine by implementing sanctions and export controls. These controls may prevent Russia from accessing necessary components for advanced technologies. Russia has found some ways to limit these impacts, importing non-controlled items that may have particular components built into them, using intermediaries such as China and Iran, or purchasing less sophisticated components from other suppliers.

Russia's Hypersonic Weapons

How do we judge who is ahead in Russia's technology competition with the United States? By most measures, the United States has a decided advantage. The United States is far ahead of Russia in AI and quantum. The United States appears to be ahead in space-based capabilities. The American civilian tech sector is significantly larger and more sophisticated than Russia's. The United States also invests significantly more in technological innovation, including in both military and civilian technologies. Hypersonic weapons may be an exception, as Russia fielded hypersonic glide vehicles and cruise missiles before the United States.

However, I argue that simply having a specific technology first or having qualitative or quantitative superiority in a certain technology is not the best way to assess who is winning a technology competition. Instead, analysts should look at who is gaining a strategic advantage through the development of these technologies. I apply this framework to Russia-U.S. hypersonic competition over the next two sections. In this section, I describe the current state of Russian hypersonic weapons.

Russia has developed at least two hypersonic nuclear-capable weapons: the Avangard hypersonic glide vehicle and the Tsirkon hypersonic cruise missile. Russia claims that a third weapon, Kinzhal, is hypersonic. However, the hypersonic nature of Kinzhal is disputed, and the weapon is likely not a true hypersonic. Kinzhal lacks the maneuverability that many analysts use as a defining feature of hypersonic weapons. It also may not maintain a hypersonic velocity over the entirety of its flight path, although reliable data on the weapon's speed in combat remains difficult to find through open sources.

Avangard was the first of the two true hypersonic weapons that Russia deployed. Avangard is a hypersonic glide vehicle that is boosted by a missile to an altitude of approximately 100 km, where it separates from the boosting missile and glides along a non-ballistic trajectory towards a given target, maneuvering during its flight.²⁵⁷ At present, the older UR-100N or the RS-28 Sarmat can boost Avangard. Plans for more survivable mobile platforms existed in the 2010s but were shuttered due to

256 Alexander Golts, "Less Money for War," Stockholm Centre for Eastern European Studies (November 14, 2024). <https://sceeus.se/en/publications/less-money-for-war/>. Accessed February 14, 2025.

257 CSIS Missile Defense Project, "Avangard," Center for Strategic and International Studies (July 31, 2021). <https://missilethreat.csis.org/missile/avangard>. Accessed February 14, 2025.

resource constraints.²⁵⁸ Avangard reportedly travels up to Mach 20 during its glide phase.²⁵⁹ Russian sources claim that its maneuverability, altitude of trajectory, and speed make it difficult to track and intercept. While it is likely more difficult to track and intercept than traditional ICBMs with MRVed or MIRVed warheads, claims that they are untrackable are exaggerations or misperceptions of Avangard's abilities. While tracking is limited, there are existing capabilities that can track a glide vehicle.²⁶⁰

Tsirkon is a hypersonic nuclear-capable cruise missile that Russia deployed by the start of 2023. Russia primarily tested Tsirkon as an anti-ship weapon fired from surface ships. Initial plans for deployment focused on frigates and corvettes, with the Admiral Gorshkov-class frigate and Buyan-M and Karakut-class corvettes set to receive Tsirkon missiles by 2026.²⁶¹ Other tests included firing Tsirkon from an underwater platform, the use of anti-submarine helicopters as guides for anti-submarine strikes with Tsirkon, and land-based anti-ship uses. Russia likely used Tsirkon in Ukraine in Spring 2024, firing the missile from land-based platforms in Crimea.²⁶² Tsirkon may reach Mach 8 or more. As with Avangard, Russian officials claim that Tsirkon is impervious to American missile defenses due to its speed, maneuverability, and flight path. However, Tsirkon may be vulnerable to Patriot, and the Ukrainian military claims that they used Patriot to intercept Tsirkon in 2024.²⁶³

Kinzhal is not a true hypersonic, given its lack of maneuverability and the possible inability to maintain speeds greater than Mach 5 for the duration of its flight. However, Russia has described Kinzhal as hypersonic. Such claims may be intentional misinformation or a misunderstanding of the technology by Russia's leadership. Kinzhal is an aeroballistic missile based on the existing Iskander missile that is fired from the Mikoyan MiG-31K or the variants of the Tupolev Tu-160. Russia has used Kinzhal in Ukraine on several occasions. While it initially penetrated Ukrainian defenses with 100% efficacy, the introduction of Patriot batteries degraded its ability to strike strategically important targets.

U.S.-Russia Hypersonic Competition

Russia deployed hypersonic weapons before any country, including the United States, when it deployed Avangard at the end of 2019. The United States has not yet fielded a hypersonic weapon. There are several American hypersonic programs at various stages of testing and development across multiple branches of the military. If deploying a weapon first determined who was winning a technology competition, then Russia would be winning. However, this removes the technologies

258 Warren, *Understanding the Determinants of Russian Strategic Nuclear Modernization since 1999*, Chapter 7.

259 CSIS Missile Defense Project, Avangard.

260 Adam Cabot, "The Avangard Threat: Is it a Game Changer?" Real Clear Defense (January 22, 2019). https://www.realcleardefense.com/articles/2019/01/22/the_avangard_threat_is_it_a_game_changer_114126.html. Accessed February 14, 2025.

261 Andrei Arkad'yev, "Nazvany sroki polucheniia VMF Rossii fregatov s giperzvukovym oruzhiem [Deadlines for the Russian Navy to receive frigates with hypersonic weapons have been named]," TV Zvezda (July 23, 2020). <https://tvzvezda.ru/news/2020723113-n6aMi.html>. Accessed February 14, 2025.

262 Brad Lendon, "Russia used an Advanced Hypersonic Missile for the First Time in Recent Strike, Ukraine Claims," CNN (February 13, 2024). <https://www.cnn.com/2024/02/13/europe/ukraine-russia-zircon-hypersonic-missile-intl-hnk-ml/index.html>. Accessed February 14, 2025.

263 Jake Epstein, "Ukraine says Russia's Unstoppable Hypersonic Missiles had Another Bad Night," Business Insider (November 19, 2024). <https://www.msn.com/en-us/news/world/ukraine-says-russia-s-unstoppable-hypersonic-missiles-had-another-bad-night/ar-AA1unbnj>. Accessed February 14, 2025.

from their strategic contexts. What is more important than having a technology first, having more of a specific technology, or having more sophisticated variants of a technology, is the strategic benefit such technologies incur.

Concerns that Russia is “leading” the United States in hypersonic weapons ignore this context. First, the United States may already be able to deploy an analog to Tsirkon or Avangard, but American strategic needs call for more sophisticated systems. Russia developed hypersonic weapons largely to be delivery vehicles for nuclear warheads—even if they have seen conventional use in Ukraine. The United States is developing hypersonic weapons for conventional purposes, requiring more advanced systems with greater accuracy.²⁶⁴ As a result, the United States will likely deploy a far more sophisticated system when it is ready.

Second, the best counter to Russia’s hypersonic weapons are more advanced missile defenses, not American hypersonic weapons. Existing missile defenses have already had some successes against Kinzhal and Tsirkon, although Avangard may be more difficult. The United States is investing in tracking systems capable of monitoring Avangard or other HGVs and may deploy systems capable of intercepting hypersonic weapons in the coming years.²⁶⁵ The Trump administration’s “Iron Dome for America” executive order specifically cites hypersonic missile defense as a necessity and orders the acceleration of the Hypersonic and Ballistic Tracking Space Sensor (HBTSS).²⁶⁶ Once such a system is deployed, any strategic advantage that Russia made by deploying hypersonic weapons would be reduced significantly.

The United States should not overcommit to directly countering or competing with these systems, as they produce only a minimal strategic benefit for Russia. Resources used to develop countering technologies or analogous capabilities are resources that cannot be dedicated to other more strategically significant challenges, which creates an opportunity cost for the United States. However, the United States should not completely ignore these small Russian benefits and American challenges. Developing and deploying improved sea-based missile defenses, deploying Patriot batteries or Terminal High Altitude Area Defense (THAAD) to protect regionally significant targets in Europe, and improving remote sensing and tracking through the development of HBTSS would significantly reduce any Russian strategic gains. Combining these technologies with deterrence-strengthening measures along NATO’s (North Atlantic Treaty Organization) Eastern Flank and in Northeast Asia would enhance their effectiveness as a regional deterrent.²⁶⁷ Furthermore, these efforts would have additional benefits, as HBTSS would strengthen American hypersonic and ballistic testing globally and developing better interceptors would also improve the ability of the United States to counter evolving threats from other actors such as China, North Korea, or Iran. Given their multiple uses, these technologies

264 Andrew W. Reddie, “Why the Alarm over Russia’s Use of Hypersonic Missiles in Ukraine is Misplaced,” *Bulletin of the Atomic Scientists* (March 31, 2023). <https://thebulletin.org/2023/03/why-the-alarm-over-russias-use-of-hypersonic-missiles-in-ukraine-is-misplaced/>. Accessed February 14, 2025.

265 Courtney Albon, “Missile Defense Agency Eyes Discriminating Space Sensor Launch by 2029,” *Defense News* (August 19, 2024). <https://www.defensenews.com/space/2024/08/19/missile-defense-agency-eyes-discriminating-space-sensor-launch-by-2029/>. Accessed February 14, 2025.

266 Donald J. Trump, “An Iron Dome for America,” *The White House* (January 27, 2025). <https://www.whitehouse.gov/presidential-actions/2025/01/the-iron-dome-for-america/>. Accessed February 14, 2025.

267 See Spenser A. Warren, “Russian Novel Nuclear Weapons and Russian War-fighting Capabilities,” *Parameters* 55 no.1 (2025), pp. 39-52. <https://press.armywarcollege.edu/parameters/vol55/iss1/5/>. Accessed April 9, 2025.

would allow the United States to mitigate or potentially even erase minimal Russian gains while limiting opportunity costs.

Finally, Russia may only get a minor strategic benefit from deploying hypersonic weapons rather than a significant strategic advantage. HGVs may improve Russia's nuclear deterrent in the future. Doing so would enhance Russian defensive abilities—ensuring the ability to prevent regime-threatening attacks against Russian territory in the face of advancing American missile defense and counterforce capabilities. These systems may also provide marginal improvements to Russian warfighting abilities, both in the nuclear and conventional domains.²⁶⁸ However, many existing Russian weapons can achieve the same kinetic effects as hypersonic weapons, while the scale at which Russia can produce them may enable Russia to overwhelm missile and air defenses, allowing them to penetrate defenses and eliminate the targets. Additionally, these systems do not provide Russia with stronger counterforce measures, as existing capabilities can overwhelm American missile and air defenses, Russia would need numerical expansion of its nuclear arsenal to pose a significant threat to American nuclear forces. Hypersonic weapons do not significantly enhance the accuracy of Russia's nuclear arsenal, while existing capabilities can already penetrate American missile defenses.²⁶⁹

When considering the strategic context, Russia is not leading the United States in hypersonic competition. Russian hypersonic capabilities provide minimal strategic benefit over the United States and fail to significantly alter the strategic status quo. Russia may currently have a slight technological advantage. However, this technological advantage does not produce a strategic advantage. It is also far smaller than Russia's broader technological inferiority in areas such as AI or quantum technologies. Additionally, the United States may soon take a decided technological lead—in addition to a strategic one—by deploying a more advanced hypersonic weapon or hypersonic missile defenses, should American leaders decide that the strategic environment requires it.

Further Applications

A similar framework could be applied to other technologies, such as space-based military capabilities and counterspace systems, AI, cyber capabilities, or quantum technologies. Additionally, it could be applied to other contexts, such as Sino-American technology competition or competition between regional rivals such as India and Pakistan or North and South Korea. Doing so would require assessing what capabilities each party has, how sophisticated those capabilities are, how they impact strategic outcomes, and how easily those impacts can be overcome.

As Eleni Ekmektsioglou argues elsewhere in this volume, rivals may choose to engage in asymmetric technological competition, developing different technologies to counter an adversary's new capabilities instead of emulating them.²⁷⁰ They may do so either because they judge it to be more militarily effective to do so or because they are incapable of emulating their rival. Assessing this competition based on the sophistication of novel technologies or simply assuming that a state which

268 Ibid.

269 See Natalie G. Montoya, "No Winning Moves: Calculated Casualties and Damages of a Nuclear Attack on the United States by Russia for First and Second Strike Scenarios" (Hon.Th., Massachusetts Institute of Technology, 2021). <https://hdl.handle.net/1721.1/139236>. Accessed April 9, 2025.

270 Eleni Ekmektsioglou, "Great Power Competition and Asymmetry: Why Countering Military Advantages is as Critical as Emulating Them."

cannot emulate its rival—or chooses not to—is “losing” a competition could produce inaccurate assumptions. In many cases, the state that is leading in the development or sophistication of a given technology may continue to lag in its competition, especially where the strategic effects of a new technology are easily overcome. Applying this framework would allow analysts and scholars to assess asymmetric competition more accurately.

Better understanding of both symmetric and asymmetric technology competition would assist strategists and policymakers in responding to new adversary technologies. Focusing on mitigating and overcoming strategic threats rather than matching Russia, China, North Korea, or other countries system for system would produce the greatest strategic benefits for the United States. It would also help prevent wasteful spending on systems with limited or no strategic impact but high opportunity costs.

Assessing Emerging Capabilities with Patent Data: U.S.-China Competition in Quantum Technologies

Juljan Krause

Emerging technologies are reshaping global competition and international security dynamics. As nations vie for technological leadership, with the private sector increasingly involved in building security and defense capabilities, patent analysis has become a critical tool for assessing innovation trajectories and identifying strategic priorities. This chapter highlights the unique value of patent data, which offer early indicators of application, diffusion, and plausible technological futures. It presents three methodological approaches—bibliometric analysis, network analytics, and machine learning—that help uncover the complexities, dynamics, and structural characteristics of contested innovation ecosystems, enabling informed decisionmaking.

A case study of U.S. and Chinese patenting activity in quantum technologies illustrates elements of patent analysis in practice. The empirical study of 15,000 patent records reveals structural differences in the two nations' quantum innovation programs: while China leads in patent volume, its quantum ecosystem is driven by numerous smaller entities, in contrast to the United States's dominance by major corporations. Both nations display a marked preference for domestic collaboration, with limited cross-border citation, reflecting strategic silos in quantum innovation.

The findings challenge current alarmist narratives of U.S. decline in quantum technologies, instead suggesting parity in efforts to advance quantum capabilities. In coupling methodological discussions with an empirical case study, the chapter seeks to demonstrate how patent analytics can provide policymakers, analysts, and strategists with a powerful tool to anticipate deep technological shifts and navigate an increasingly competitive global landscape characterized by intensifying great-power rivalry.

Introduction: Defining Emerging Technologies

The global competition for technological dominance, particularly in fields such as artificial intelligence (AI), semiconductors, quantum technology, robotics, and bioengineering, has transformed the landscape of international relations in the 21st century. These emerging technologies are not merely commercial pursuits; they are potential sources of strategic advantage that shape security, influence economic power, and may alter the dynamics of geopolitical stability. Nowhere is this competition more visible than in the rivalry between the United States and China, where each nation is invested in advancing technological capabilities to secure their place in a world characterized by rapid and often disruptive innovation and an evolving contest over the values, principles, and standards underpinning the international system.²⁷¹

271 Tai Ming Cheung, *Innovate to Dominate: The Rise of the Chinese Techno-Security State* (Ithaca, NY: Cornell University Press, 2022); Alexandra Gheciu and William Curti Wohlforth, eds., *The Oxford Handbook of International Security*, The Oxford Handbooks of International Relations (Oxford, UK: Oxford University Press, 2018).

Emerging technologies, by their nature, present a paradox of significance and uncertainty. The term “emerging” suggests novelty and irreducibility that make them functionally different from existing objects, yet the term is imprecise.²⁷² By construction, emerging technologies are in the early stages of development and deployment, with minimal performance data and limited real-world application. For the purposes of this chapter, avoiding the pitfalls of attempting an exhaustive definition, emerging technologies are characterized by five attributes: (i) the degree of their novelty, real or perceived; (ii) their growth rate and diffusion; (iii) their coherence or chance to make a lasting impact; (iv) the prominence and visibility of such an impact; and (v) the degrees of uncertainty and ambiguity about their application and implementation:

Table 1: Key Attributes of Emerging Technologies²⁷³

Attribute	Description
Novelty	Novelty in design or function, whether real or perceived
Growth and Diffusion	Rapid growth and widespread adoption
Coherence	Likelihood of creating a sustained and meaningful impact
Prominence	High visibility and influence
Uncertainty	Ambiguity in application and outcomes

Taxonomies of this type allow for divergent levels of “emerging-ness” in capturing innovation across sectors: not every invention will score equally across all five metrics. Emerging technologies of high quality, then, are best construed as a set of innovations that promise novel solutions, significant impact, and non-trivial applications that matter to defense and security.

For both scholars and policymakers alike, the following question arises: How can the progression of these capabilities be measured when they are, by definition, still in flux? And, critically, how can insight into an adversary’s technology agenda be obtained when direct observation is often limited? Addressing these challenges is increasingly vital as emerging technologies possess the potential to reshape international security, standards and governance models, and the very norms underpinning the international rules-based order.

This chapter argues that patent analysis offers a robust approach to tackling the complex task of assessing emerging technologies characterized by (i) to (v) above. Patents, serving as formal records of intellectual property, provide detailed descriptions of innovations at the point of their inception. Unlike other indicators, patents reveal both the intention behind a technology and its potential applications. They are particularly valuable because they capture the early stages of technological development, often before products reach the market or are fully implemented. By examining

272 Timothy O’Connor and Hong Yu Wong, “Emergent Properties,” in *The Stanford Encyclopedia of Philosophy*, Edward N. Zalta, ed., Summer 2015 (Metaphysics Research Lab, Stanford University, 2015). <https://plato.stanford.edu/archives/sum2015/entries/properties-emergent/>. Accessed April 9, 2025.

273 Daniele Rotolo, Diana Hicks, and Ben R. Martin, “What Is an Emerging Technology?,” *Research Policy* 44, no. 10 (December 1, 2015), pp. 1827–43. <https://doi.org/10.1016/j.respol.2015.06.006>. Accessed April 9, 2025.

patents, the direction of technological research can be inferred, and major actors and collaborators identified, gauging the strategic priorities that drive national innovation efforts at home and abroad.

The purpose of this chapter is therefore to provide a high-level overview of assessing emerging capabilities with patent analytics in practice. It outlines three key methodological approaches to patent analysis—traditional bibliometric tools, statistical network analysis, and machine learning techniques—that provide decisionmakers with a more nuanced understanding of these technologies.

Traditional bibliometric analysis offers insights into citation patterns and geographic clustering, revealing which nations or regions are leading in specific fields. Statistical network analysis further enhances this understanding by mapping relationships between patent clusters, their inventors and funders, helping to identify technological hubs and the broader structural dynamics of innovation networks. Finally, machine learning techniques, including topic modeling and keyword analysis, allow for advanced textual analysis of patent content, enabling the identification of thematic trends and potential future applications.

Through a comparative case study of patenting activity in quantum technology, this chapter illustrates how the United States and China approach innovation in this critical field. Following the methodological discussion, the second part of this chapter develops an empirical case study, using a purpose-built dataset of 15,000 patent records in quantum computing and quantum communication to give practical examples of how patent analysis with a view to national and international security issues may be performed. Ultimately, the chapter positions patent analysis as a powerful tool for assessing emerging technological capabilities, especially in the absence of complete information—a method that can help nations anticipate, and policymakers shape, the technological landscape of the future marked by great power rivalry.

Background: The International Patenting Landscape

Patents are one of the most comprehensive and accessible sources of information on technological innovation. Defined by the World Intellectual Property Organization (WIPO) as “an exclusive right granted for an invention, which is a product or a process that provides, in general, a new way of doing something, or offers a new technical solution to a problem,” patents serve as signals of both technological novelty and commercial intent.²⁷⁴ They incentivize innovation by protecting ideas from unauthorized use and exploitation by third parties.²⁷⁵

The growing role of the private sector in security-related innovation further underscores the value of patent data in understanding technological progress. Traditionally, military technologies were developed within government facilities and often shielded from public view. However, contemporary innovation in areas like AI, quantum technology, and autonomous systems is frequently driven by private companies whose patents are accessible, motivated by the prospect of future commercial gains and, in many cases, incentivized by government partnerships. In the United States, federal research and development (R&D) funding has dropped since the 1960s, “from 1.86% of GDP in 1964

274 WIPO, “Patents,” About IP (November 15, 2021). <https://www.wipo.int/patents/en/index.html>. Accessed April 9, 2025.

275 Alan L. Porter et al., “Emergence Scoring to Identify Frontier R&D Topics and Key Players,” *Technological Forecasting and Social Change* 146 (September 1, 2019), pp. 628–43. <https://doi.org/10.1016/j.techfore.2018.04.016>. Accessed April 9, 2025.

to just 0.66% of GDP in 2016,²⁷⁶ pointing to the growth of private sector involvement relative to government funding.²⁷⁷

This shift has made patent analysis a viable method for observing emerging capabilities that may directly impact national security. As governments increasingly rely on private-sector partnerships for delivering critical advancements, and the private sector wanting to protect intellectual property, patents offer insights into technologies that, while not yet fully operational, could soon reshape security and defense capabilities, cybersecurity frameworks, and the global strategic balance.

In this competitive landscape, the United States and China are the clearest examples of nations leveraging patent data as part of their technology strategies. China’s patent activity has surged in recent years, with its State Intellectual Property Office (SIPO) recording a substantial increase in applications over many years. In 2023, patent registrations in China, the United States, Japan, South Korea, and Europe made up about 85% of total global filings, with China leading by a significant margin.

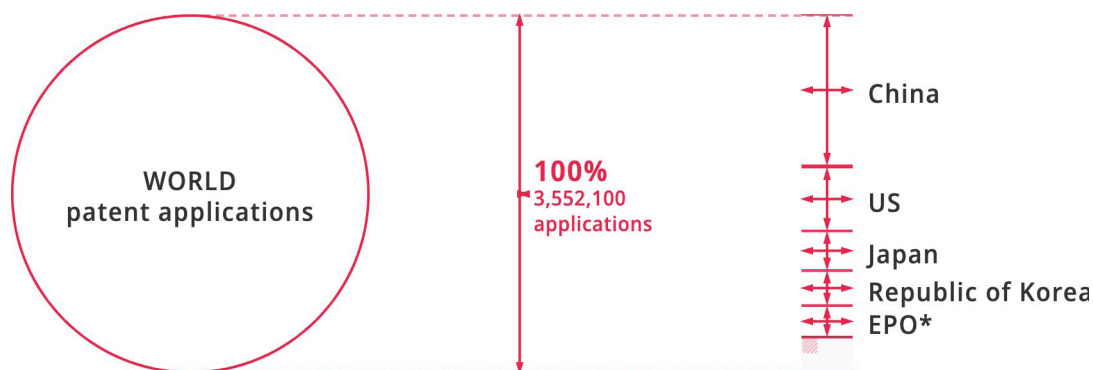


Figure 1: In 2023, the combined share of the top five patent offices constituted a substantial 85% of the world’s total patent output (EPO = European Patent Office).
Source: WIPO Statistics Database.

China’s patent output rate has been rising significantly over the past 15 years. In 2011, it overtook the United States to become the country filing the largest number of patents.²⁷⁸ In 2023, its filing rate exceeded that of the United States by more than 300%.

276 Herbert S. Lin, “The Stanford Emerging Technology Review” (Stanford CA: Stanford University, 2023), p. 6.

277 Andrew Feickert et al., “U.S. Ground Forces Robotics and Autonomous Systems (RAS) and Artificial Intelligence (AI): Considerations for Congress,” U.S. Congressional Research Service, no. R45392 (November 20, 2018), p. 47.

278 Albert G. Z. Hu, Peng Zhang, and Lijing Zhao, “China as Number One? Evidence from China’s Most Recent Patenting Surge,” *Journal of Development Economics* 124 (January 1, 2017), pp. 107–19. <https://doi.org/10.1016/j.jdeveco.2016.09.004>. Accessed April 9, 2025.

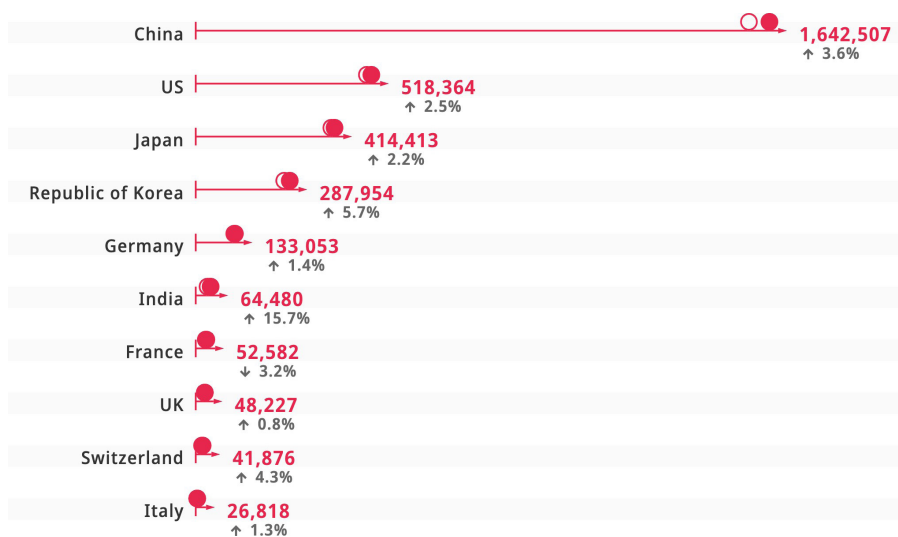


Figure 2: The top 10 patenting countries by count of patent applications.
Source: WIPO Statistics Database.

China has made significant progress across a wide range of advanced technologies deemed critical for U.S. national security.²⁷⁹ Some sources suggest that China now outperforms the United States not just in terms of patent output but other technology indicators also, warning that “Western democracies are losing the global technological competition” while China is positioning itself “as the world’s leading science and technology superpower.”²⁸⁰ Former U.S. DOD officials find that the United States lags behind in 12 core technologies as measured by patent registrations.²⁸¹

Limitations of Patent Analysis and Complementary Approaches

While patent analysis offers valuable insights into technological trends and innovation ecosystems, it is not without limitations. China especially has been accused of strategically inflating its number of patents, implying that many of the technologies and processes it has sought to protect are of little

279 Cheung, *Innovate to Dominate*; Lindsay Gorman, “China’s Data Ambitions: Strategy, Emerging Technologies, and Implications for Democracies,” Commentary from the Center for Innovation, Trade, and Strategy (Washington, DC: National Bureau of Asian Research, August 14, 2021), <https://www.nbr.org/publication/chinas-data-ambitions-strategy-emerging-technologies-and-implications-for-democracies/> (accessed April 9, 2025); Todd S. Sechser, Neil Narang, and Caitlin Talmadge, “Emerging Technologies and Strategic Stability in Peacetime, Crisis, and War,” *Journal of Strategic Studies* 42, no. 6 (September 19, 2019), pp. 727–35, <https://doi.org/10.1080/01402390.2019.1626725>, (accessed April 9, 2025); Jon Schmid, “Rethinking Who’s Winning the U.S.-China Tech Competition,” RAND Corporation, The RAND Blog (blog) (August 16, 2023), <https://www.rand.org/pubs/commentary/2023/08/rethinking-whos-winning-the-us-china-tech-competition.html> (accessed April 9, 2025); Marianne Schneider-Petsinger et al., “U.S.–China Strategic Competition: The Quest for Global Technological Leadership,” Chatham House Research Paper (November 2019), p. 45; Xiangning Wu, “Technology, Power, and Uncontrolled Great Power Strategic Competition between China and the United States,” *China International Strategy Review* 2, no. 1 (June 1, 2020), pp. 99–119, <https://doi.org/10.1007/s42533-020-00040-0> (accessed April 9, 2025).

280 Jamie Gaida et al., “Policy Brief: ASPI’s Critical Technology Tracker: The Global Race for Future Power,” Policy Brief (Canberra: Australian Strategic Policy Institute, 2023).

281 Josh Luckenbaugh, “U.S. Falling Behind China in Critical Tech Race, Report Finds,” *National Defense* (July 17, 2023). <https://www.nationaldefensemagazine.org/articles/2023/7/17/us-falling-behind-china-in-critical-tech-race-report-finds>. Accessed April 9, 2025.

value.²⁸² Other sources of biases in patenting practices, particularly the over-citation of domestic innovations coupled with downplaying the impact of foreign technology, can distort the visibility of international collaboration and may obscure the actual flow of knowledge across borders. Furthermore, the time lag in patent publications, combined with the possibility of certain critical technologies being withheld for security reasons, introduces challenges in assessing real-time technological capabilities with patent analysis.

A major critical concern is the possible disconnect between patent filings and substantive technological advancements. Typically, skilled patent officers—experts in their technology domains—remove applications that are not to standard. Where such oversight is limited, however, patents, in some cases, may reflect “cheap talk” or strategic bluffing rather than genuine innovation. If it is possible to file patents primarily to signal intent, secure funding, or establish defensive intellectual property positions rather than to represent market-ready technologies, the value of analyzing patent data will be compromised. Additionally, the percentage of patented technologies that ultimately reach the market and prove commercially successful may be relatively low, highlighting the need for caution when using patent volume as a measure of innovation.

Patent analysis is one of several methodologies available for studying emerging technologies, and it is crucial to recognize its boundaries in comparison to other approaches. Quantitative methods, such as citation network analysis, provide structural insights but may find it difficult to identify contextual nuances. Qualitative approaches, including expert interviews and case studies, can offer depth and granularity that patent data alone may not provide. Other proxies, such as venture capital investments, R&D expenditures, or academic publication trends, can complement patent analysis to paint a fuller picture of technological landscapes.

Knowledge of the future is necessarily imperfect, which makes distinguishing high-impact patents from marginal ones challenging and is subject to significant degrees of uncertainty. The risk of state-sponsored industrial espionage may translate into concerns about intellectual property theft that can lead some firms to delay patenting or opt for trade secrets, reducing the visibility of technological progress in certain fields. These geopolitical dynamics complicate the use of patents as a universal proxy for innovation and necessitate careful contextual interpretation.

Despite these challenges, patent analysis remains a valuable tool for understanding emerging technological capabilities, particularly in the face of imperfect information about the future. Patents are inherently a speculative proxy, but they provide an accessible and systematic way to gauge technological trajectories, strategic priorities, and innovation ecosystems. Their structured nature and widespread availability—thanks to systemic reviews by expert communities at patent offices, and globally agreed standards—make them one of the few quantifiable measures available to researchers and policymakers alike.

While acknowledging the limitations inherent in patent data, the approach put forward in this chapter complements other proxies and methodologies to offer a unique lens into technological

282 Cheung, *Innovate to Dominate*; Jiashun Huang et al., “Technology and Innovation in China: A Patent Citation-Based Analysis,” *Science, Technology and Society* (June 20, 2020), <https://doi.org/10.1177/0971721820932020> (accessed April 9, 2025); Alexander Kersten, Gabrielle Athanasia, and Gregory Arcuri, “What Can Patent Data Reveal about U.S.-China Technology Competition?,” *Critical Questions*, Center for Strategic and International Studies (September 19, 2022), <https://www.csis.org/analysis/what-can-patent-data-reveal-about-us-china-technology-competition> (accessed April 9, 2025).

competition. The point is not to claim that patents measure absolute innovation, but rather to leverage them as one piece of a broader analytical framework for navigating uncertainty in rapidly evolving technological landscapes. The growing trend of private-sector-led innovation, especially in military and security technologies, and China's sustained efforts to dominate the patenting landscape, strengthens the case for using patents as indicators of emerging technology trends, even where qualifications regarding quality and impact will have to be made.

Examples of Patent Analysis in Technology Forecasting

For scholars and policymakers focused on emerging technologies, patents are particularly valuable as they provide early indicators of technological direction and intent. Patents effectively forecast a technology's probable future pathways, functioning as "indicators of technological emergence" in fields where academic research is rapidly translating into marketable inventions, alongside characterizing the ecosystem of actors involved in their production.²⁸³

For instance, in a study of 4.8 million U.S. patents and 32 million research articles that measures the "distance" between academic publications and patented inventions, researchers have found that publications in nanotechnology and computer science have relatively short distances to travel until they transform into tangible patents, meaning they are quickly integrated into commercial applications. This pattern is indicative of the highly translational potential of these fields.²⁸⁴ Short distances of this kind point to opportunities to effect substantial policy impact as the transmission mechanism between funding and visible output is fairly straightforward.

Traditionally, patent analysis serves as a barometer of technological change and the direction of knowledge flows. Early works in the field utilized patent statistics to explore macroeconomic sectoral changes, pioneering the understanding of how patents reflect economic shifts in innovation-intensive sectors.²⁸⁵ Later, patent citations became central to understanding knowledge diffusion, allowing researchers to map out how innovation spreads geographically and temporally. For example, patent citations offer insights into localized knowledge spillovers, showing that patents tend to cite others within the same region, revealing the geographic clustering of technological development.²⁸⁶

Today, the analysis of patent citations is integral to the study of knowledge diffusion across sectors and industries, with network models of patent citations providing a clear view of how innovation feeds through innovation systems.²⁸⁷ Studies have demonstrated repeatedly the robustness of patent citations as indicators for assessing the impact of foundational technologies and the pathways

283 Porter et al., "Emergence Scoring to Identify Frontier R&D Topics and Key Players."

284 Mohammad Ahmadpoor and Benjamin F. Jones, "The Dual Frontier: Patented Inventions and Prior Scientific Advance," *Science* 357, no. 6351 (August 11, 2017), pp. 583–8. <https://doi.org/10.1126/science.aam9527>. Accessed April 9, 2025.

285 Keith Pavitt, "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory," *Research Policy* 13, no. 6 (December 1, 1984), pp. 343–73. [https://doi.org/10.1016/0048-7333\(84\)90018-0](https://doi.org/10.1016/0048-7333(84)90018-0). Accessed April 9, 2025.

286 Adam B. Jaffe, Manuel Trajtenberg, and Rebecca Henderson, "Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations," *The Quarterly Journal of Economics* 108, no. 3 (1993), p. 577. <https://doi.org/10.2307/2118401>. Accessed April 9, 2025.

287 Patents cite other patents as "prior art" similar to the ways in which an academic would cite the works of colleagues where they have shaped the author's thinking.

through which knowledge disseminates globally,²⁸⁸ making patent data a critical resource for understanding both the emergence of key innovations as well as the structure of global research networks that enable their proliferation. Patent data also act as financial signals that reflect investor confidence in the viability and relevance of a company's research and development efforts.²⁸⁹

Patent Analytics as a Component of Open Source Intelligence

Open Source Intelligence (OSINT) refers to the collection, analysis, and application of information gathered from publicly accessible sources to support strategic decisionmaking in security, governance, and technology management, both in the public and private sectors. Patent analytics has emerged as a valuable component of OSINT, providing governments and security agencies with an accessible, legally available data source that reveals insights into global technological progress. OSINT has gained prominence as a vital component of modern intelligence practices, offering an ethically transparent means of understanding the intentions and capabilities of adversaries, allies, and commercial actors.²⁹⁰ Patent data, with its detailed descriptions of inventions, is well suited to this purpose, as it allows analysts to track both the intentions and achievements of private and public sector entities worldwide.

In the context of OSINT, patent analysis serves as a tool for identifying early indicators of technological advancements, which can be particularly useful in monitoring the activities of foreign defense contractors, research institutions, and private firms engaged in dual-use or high-stakes technology fields. Patent filings often provide information on emerging applications and can reveal the strategic focus areas of key players, especially in countries with robust government-industry collaborations, such as China's government-linked tech companies. Through systematic patent analysis, intelligence agencies can create a roadmap of where and how resources are being allocated in fields relevant to national security.

One advantage of using patent data as part of OSINT is the broad international coverage provided by major patent databases, such as the World Intellectual Property Organization (WIPO) and national patent offices. These databases allow for near real-time tracking of technological development across borders, helping OSINT analysts monitor trends at both national and international levels. For example, rapid increases in AI patent filings related to image recognition in certain countries could indicate heightened interest in surveillance technologies, providing intelligence on likely strategic priorities and security applications. Leveraging patent data for OSINT also supports insight into the

288 Juan Alcácer and Michelle Gittelman, "Patent Citations as a Measure of Knowledge Flows: The Influence of Examiner Citations," *The Review of Economics and Statistics* 88, no. 4 (2006), p. 774.

289 Diego Useche, "Are Patents Signals for the IPO Market? An EU–U.S. Comparison for the Software Industry," *Research Policy* 43, no. 8 (October 1, 2014), pp. 1299–1311. <https://doi.org/10.1016/j.respol.2014.04.004>. Accessed April 9, 2025.

290 Michael Bazzell and Jason Edison, *OSINT Techniques: Resources for Uncovering Online Information* (Independently published, 2024); João Rafael Gonçalves Evangelista et al., "Systematic Literature Review to Investigate the Application of Open Source Intelligence (OSINT) with Artificial Intelligence," *Journal of Applied Security Research* 16, no. 3 (July 3, 2021), pp. 345–69, <https://doi.org/10.1080/19361610.2020.1761737> (accessed April 9, 2025); Yong-Woon Hwang et al., "Current Status and Security Trend of OSINT," *Wireless Communications and Mobile Computing* 2022, no. 1 (2022), <https://doi.org/10.1155/2022/1290129> (accessed April 9, 2025); Randolph H. Pherson and Richards J. Heuer, *Structured Analytic Techniques for Intelligence Analysis*, third edition (Thousand Oaks, CA: CQ Press, 2020).

commercial dimensions of such applications, especially where businesses are state-sponsored or heavily subsidized.²⁹¹

Moreover, patent analytics within OSINT frameworks supports transparency in intelligence gathering, as it relies on data that is publicly accessible and legally available. This openness is particularly advantageous in diplomatic contexts, where intelligence derived from public records is less likely to lead to accusations of espionage or illicit data acquisition. For instance, patent analytics can be shared among allied nations as part of a collective defense strategy, enhancing mutual awareness of technological threats without the complications that arise from sharing classified material.

While patent data is valuable, it also presents certain challenges within OSINT. Governments and private companies may use patents strategically, either by over-patenting to obscure true innovation priorities or by withholding patents in areas deemed sensitive for national security. Awareness of these potential biases and shortcomings is crucial, highlighting the need to corroborate patent-derived intelligence with other OSINT or classified sources where possible to build a more complete picture.

Methodological Approaches to Patent Analysis

To take stock, patent analysis is a multifaceted tool that can reveal technological trends, illuminate the networks of innovation, and provide predictive insights into emerging capabilities. The field of patent analysis has matured significantly, drawing from bibliometrics, network science, and machine learning to address the complexities of understanding technological development. This section outlines three primary approaches—bibliometric analysis, network analytics, and machine learning—that are instrumental in capturing the depth and diversity of information within patent datasets.

Traditional Bibliometric Analysis

Bibliometric analysis is one of the earliest and most widely used methods in patent analysis, focusing on the examination of citation data and collaborative patterns. Patents, much like academic publications, contain citations that link inventions to prior knowledge, creating a network of references that can be used to trace the flow of innovation. Bibliometric tools typically assess patent citations, inventor affiliations, and the geographical distribution of patents, providing a snapshot of technological diffusion and the regional concentration of innovation.

The foundations of bibliometric analysis in patent research were laid in studies into sectoral patterns of innovation, which identified industry-specific trends in technological development.²⁹² Subsequent research extended these concepts to examine the localization of innovation. Work on knowledge spillovers, for example, used patent citations to show that knowledge flows are often geographically bound. This line of research demonstrated that domestic patents are more likely to cite other domestic patents, suggesting that innovation ecosystems are heavily influenced by regional proximity and industry-specific networks.²⁹³

291 Golden Owl, “Leveraging OSINT for Market Intelligence: A Strategic Advantage,” Medium (blog), February 5, 2024. <https://goldenowl.medium.com/leveraging-osint-for-market-intelligence-a-strategic-advantage-7cbb2e428fb9>. Accessed April 9, 2025.

292 Pavitt, “Sectoral Patterns of Technical Change.”

293 Jaffe, Trajtenberg, and Henderson, “Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations.”

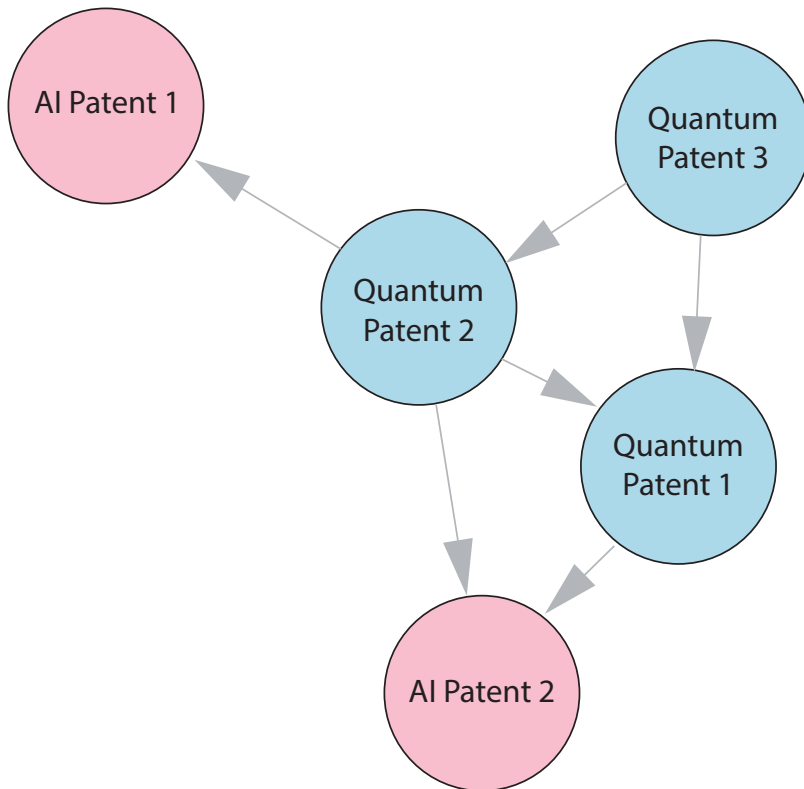


Figure 3: Illustrative example of a patent citation network in which edges represent citation links as revealed in bibliometric analysis.

The bibliometric approach to patent analysis has evolved with the increasing complexity and volume of patent data. By the 1990s, patents had become a primary data source for economists and policymakers interested in understanding the drivers of economic growth and technological change on national and global scales.²⁹⁴ Today, patent citation analysis is widely used to map knowledge diffusion across borders and assess the impact of patents within specific technological domains. This method is particularly useful for identifying emerging fields and tracking the influence of foundational patents that serve as technological “backbones” within their respective domains.

In addition to individual patent impact, bibliometric analysis allows researchers to examine the collaborative networks within patenting activity. Co-inventorship analysis, for instance, can reveal patterns of collaboration between institutions, firms, and countries. Studies on patent collaboration have shown that cross-border patenting activity is often associated with higher innovation quality, as measured by subsequent citations and market relevance. The study of international patent collaborations is increasingly important in understanding the globalized nature of technology development and the strategic alliances that shape innovation on a micro-level.

294 Zvi Griliches, “Patent Statistics as Economic Indicators: A Survey,” *Journal of Economic Literature* 28, no. 4 (1990), pp. 1661–1707. Accessed April 9, 2025.

Statistical Network Analysis

Baseline bibliometric studies often are the starting point for more complex statistical research into the dynamics by which patent networks form, enabled by exciting new research in graph theory and network modeling that supports visualizing such graphs and computing meaningful summary indicators.

Network analytics offers a powerful framework for examining on a deeper level the structure of relationships within patent data, providing insights into the interconnectedness of technological fields and the clustering of innovations. Statistical network analysis involves creating complex graphs of patent citations, connections between inventors, and keyword associations to identify clusters of related patents and influential “hubs” within the network. These analyses help to identify core technologies, innovation clusters, and the pathways through which knowledge flows within and across technological domains.

Network analysis in patent research has proven particularly valuable for identifying fundamental inventions that drive innovation within an industry. For instance, a study of international patents in the global automobile industry identifies clusters of patents that represented essential innovations in vehicle technology.²⁹⁵ These core clusters, or “backbones,” can serve as accelerators of innovation by facilitating the development of related technologies. By examining the central nodes and links within a patent network, researchers can identify high-impact technologies and key actors who shape the trajectory of an entire sector.

Network analytics also provides insights into the strategic priorities of different countries or organizations. For example, in the context of quantum technologies, patents filed by major firms and research institutions can be mapped to reveal concentrations of research efforts in certain areas, such as quantum cryptography or quantum computing hardware (the next section offers a case study of 15,000 quantum technology patents to illustrate this approach in practical terms). Such analyses are especially relevant in fields where technological leadership is contested, as they help reveal the areas where investment and research are most intense.

Network analysis in patent studies often employs social network metrics, such as centrality and clustering coefficients, to quantify the influence of particular patents or inventors. Studies in fields like telecommunications and biotechnology have demonstrated that patents with high centrality in the citation network tend to be more influential and foundational for subsequent innovation. This type of analysis is particularly useful in assessing the impact of disruptive technologies, as central patents often signal foundational knowledge that underpins further development. Beyond individual patents, network analytics can reveal larger innovation ecosystems by mapping relationships among organizations and countries. The approach is commonly used to examine regional and national innovation systems, providing insights into the role of governmental and private sector actors in driving technological advancement.

Machine Learning for Enhanced Patent Analysis

Machine Learning (ML) has introduced sophisticated techniques for analyzing large patent datasets, offering tools that go beyond traditional citation analysis and network mapping. Text mining,

295 Yan Lin, Jian Chen, and Yan Chen, “Backbone of Technology Evolution in the Modern Era Automobile Industry: An Analysis by the Patents Citation Network,” *Journal of Systems Science and Systems Engineering* 20, no. 4 (December 2011), pp. 416–42. <https://doi.org/10.1007/s11518-011-5181-y>. Accessed April 9, 2025.

topic modeling, and keyword analysis are among the machine learning approaches that enable a deeper understanding of the content within patents, allowing researchers to uncover thematic trends and predict future developments within a technological field.

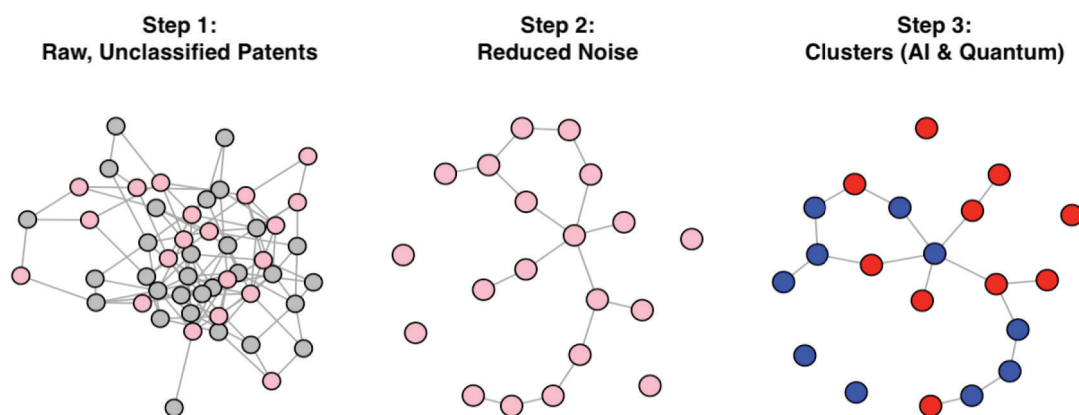


Figure 4: Illustrative example of a three-step Machine Learning process that filters and groups patent records in clusters of interest, such as AI and quantum technologies.

The visualization above illustrates a three-step process that demonstrates how ML refines and organizes patent data to uncover meaningful insights. In the first step, a dataset is assembled from source data, such as WIPO or EPO databases. It will contain patents of interest (such as, in this example, AI and quantum technology patents, colored in pink) and a large number of irrelevant patents (colored in gray).

This unfiltered dataset represents the starting point of analysis, containing significant noise that obscures critical patterns to the human eye. In the second step, an algorithm is applied to remove patents unrelated to AI or quantum technologies, effectively reducing noise and isolating only the relevant data. The algorithm will have been trained, e.g. on a small set of samples, or it learns as it goes along—the training of algorithms constitutes a vast subfield in ML research.²⁹⁶

Finally, in the third step, the refined dataset is organized into distinct clusters, grouping AI-related patents (red) together in one cluster and quantum-related patents (blue) in another. This organization reveals underlying structures in the data, such as technology trends or collaborative networks, that are otherwise difficult to detect in unstructured datasets.

This approach exemplifies the utility of machine learning in patent analytics, where algorithms such as classification, clustering, and topic modeling can process large, complex datasets with precision. By identifying and grouping patents based on shared characteristics—such as thematic relevance or citation patterns—ML can provide researchers and policymakers with insights into emerging technological fields. As demonstrated in this example, machine learning transforms raw,

296 Shai Shalev-Shwartz, *Understanding Machine Learning*, 1st edition (New York: Cambridge University Press, 2014); Kevin P. Murphy, *Probabilistic Machine Learning: Advanced Topics* (Cambridge MA, London: The MIT Press, 2023).

unstructured data into a coherent representation of innovation landscapes, enhancing the ability to monitor technological trajectories that an adversary may be pursuing.

Beyond such clustering, text mining and natural language processing (NLP) techniques have made it possible to analyze the vast amount of textual data in patent documents—patent registration records typically include several pages of text that explain the purpose, application, and novelty of the patent. By extracting key terms and phrases from patent abstracts, claims, and descriptions, NLP tools can identify emerging trends and categorize patents by their thematic content. Topic modeling, a popular NLP technique, uses algorithms such as Latent Dirichlet Allocation (LDA) to classify patents into topics based on word patterns within the text.²⁹⁷ This method is particularly effective for identifying clusters of related patents within very large datasets, enabling researchers to map the evolution of specific technologies over time.

Closely related, keyword analysis, often used alongside topic modeling, provides additional granularity in identifying the focus areas of patent activity. ML models trained on patent text can highlight key words that are characteristic of specific technological fields or applications, allowing researchers to trace the development of niche technologies. For example, in the analysis of AI patents, machine learning algorithms can track the use of terms like “neural network,” “reinforcement learning,” and “natural language processing” to identify which AI subfields are experiencing the most growth and investment by which sector or country. This approach enables a more nuanced understanding of the priorities within a technology, and highlights changing narratives, helping stakeholders to anticipate where future innovations are likely to occur.

Predictions of plausible future innovation trajectories matter a great deal to the commercial sector. Predictive modelling is a final area where ML enhances patent analysis, allowing for the identification of patents with high commercialization potential.²⁹⁸ Examples include models based on “patent power” and “expansion potential” to forecast core technologies, such as in the U.S. electronics industry, demonstrating how predictive analysis can support more informed R&D and market strategies.²⁹⁹

Methodological approaches to patent analysis, from traditional bibliometric tools to advanced ML techniques, provide a comprehensive framework for understanding the trajectory of emerging technologies. Bibliometric analysis offers initial, high-level insights into citation patterns and regional innovation hubs, while network analytics helps reveal deeper structural characteristics of technological ecosystems and highlight core innovations. ML, with its capacity for thematic and predictive analysis, brings additional capabilities to patent studies, enabling researchers to capture trends that might otherwise remain unobservable in large datasets. Together, these methods offer a robust toolkit for assessing the competitive landscape of emerging technology development, and estimating the progress that adversaries make.

297 David M. Blei, Andrew Y. Ng, and Michael I. Jordan, “Latent Dirichlet Allocation,” *Journal of Machine Learning Research* 3, Jan (2003), pp. 993–1022.

298 Youngjin Seol et al., “Dynamic Technology Impact Analysis: A Multi-Task Learning Approach to Patent Citation Prediction” (arXiv, November 14, 2024), <https://doi.org/10.48550/arXiv.2411.09184> (accessed April 9, 2025); Mei-Hsin Wang and Hui-Chung Che, “Intellectual Capital Forecasting for Invention Patent through Machine Learning Model,” *Journal of Intellectual Capital* 25, no. 7 (November 13, 2024), pp. 129–50, <https://doi.org/10.1108/JIC-12-2023-0286> (accessed April 9, 2025).

299 Serkan Altuntas, Turkyay Dereli, and Andrew Kusiak, “Forecasting Technology Success Based on Patent Data,” *Technological Forecasting and Social Change* 96 (July 2015), pp. 202–14. <https://doi.org/10.1016/j.techfore.2015.03.011>. Accessed April 9, 2025.

Case Study: U.S.-China Competition Over Quantum Technologies

This section develops an empirical case study to illustrate the application of statistical network analysis for assessing emerging capabilities using patent data. It provides insight into the structural characteristics of the American and Chinese quantum technology landscape, notably efforts in quantum computing and quantum communication that reflect in the patenting activities and strategies of both countries. From an international security perspective, it highlights the kinds of contributions patent analysis can make to the study of emerging technologies.

Traditionally the world's leading nation in technology development, in the domain of quantum technologies, the United States has come under sustained pressure from China. For the Chinese leadership, quantum capabilities will offer considerable reputational and signalling gains whilst providing the leadership with a dual-use technology for advancing its domestic cyber surveillance program, at the same time protecting the country against adversarial cyber activities.³⁰⁰ Moreover, a leadership position in quantum technologies could provide China with a new source of non-kinetic deterrent capability that would greatly support the country's efforts at alliance building, since markets for extended deterrence are "likely to significantly shift with the inclusion of more capabilities,"³⁰¹ kinetic or otherwise.

The United States has certainly recognized the challenges that a confident and emboldened strategic rival poses. In May 2022, the White House issued a National Security Memorandum on quantum information science (QIS). It makes "clear that America's continued technological and scientific leadership will depend, at least in part, on the Nation's ability to maintain a competitive advantage in quantum computing and QIS."³⁰² In August 2023, an Executive Order limited U.S. investment in Chinese quantum technology outfits, saying that Chinese quantum capabilities "pose significant national security risks, such as the development of more sophisticated weapons systems, breaking of cryptographic codes, and other applications that could provide [China] with military advantages."³⁰³

Since then, both countries have ramped up their rhetoric and signaled resolve to become the world leader in quantum technologies. This intensifying rivalry over quantum technologies between the two nations prompts the question: what have they achieved so far in terms of visible patent output? The below case study explores this question. It seeks to make an empirical contribution to the

300 Elsa B. Kania, "China's Quest for Quantum Advantage—Strategic and Defense Innovation at a New Frontier," *Journal of Strategic Studies* 44, no. 6 (September 19, 2021), pp. 922–52, <https://doi.org/10.1080/01402390.2021.1973658> (accessed April 9, 2025); Jon R. Lindsay, ed., *China and Cybersecurity: Espionage, Strategy, and Politics in the Digital Domain* (New York: Oxford University Press, 2015); Jane Vaynman and Tristan A. Volpe, "Dual Use Deception: How Technology Shapes Cooperation in International Relations," *International Organization* 77, no. 3 (March 2023), pp. 599–632, <https://doi.org/10.1017/S0020818323000140> (accessed April 9, 2025).

301 Rupal N. Mehta, "Extended Deterrence and Assurance in an Emerging Technology Environment," *Journal of Strategic Studies* 44, no. 7 (November 10, 2021), p. 977. <https://doi.org/10.1080/01402390.2019.1621173>. Accessed April 9, 2025.

302 The White House, "National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems," NSM-10 § (May 4, 2022). <https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2022/05/04/national-security-memorandum-on-promoting-united-states-leadership-in-quantum-computing-while-mitigating-risks-to-vulnerable-cryptographic-systems/>. Accessed April 9, 2025.

303 The White House, "President Biden Signs Executive Order on Addressing United States Investments in Certain National Security Technologies and Products in Countries of Concern" (August 9, 2023). <https://bidenwhitehouse.archives.gov/briefing-room/statements-releases/2023/08/09/president-biden-signs-executive-order-on-addressing-united-states-investments-in-certain-national-security-technologies-and-products-in-countries-of-concern/#:~:text=Today%2C%20President%20Joe%20Biden%20signed,in%20entities%20engaged%20in%20activities>. Accessed April 9, 2025.

study of emerging technologies and international security, whilst at the same providing analysts and policymakers with a step-by-step overview of performing patent analysis in practice.

Data Sources

In a first step, a database of 15,000 patent records was assembled. Data was retrieved from the Global Patent Index (GPI), a database maintained by the European Patent Office (EPO), via the GPI Web and API interfaces. Each patent record held in the GPI database is labeled with at least one CPC (Cooperative Patent Classification) or IPC (International Patent Classification) entry and is thus retrievable by selecting the appropriate classification tree.

For instance, G06N 10/00 captures “Quantum computers, i.e. computer systems based on quantum-mechanical phenomena.” While it is straightforward to automate data collection following a retrieval approach based on classifiers, a significant number of patents typically sit in fringe subgroups that are difficult to anticipate. Over-reliance on classification codes can pull irrelevant data while missing out positives.³⁰⁴ Therefore, the CPC/IPC code search was combined with a keyword filtering approach to retrieve patent families.

The EPO defines a patent family as “a collection of patent applications covering the same or similar technical content.”³⁰⁵ This grouping is necessary when an inventor registers patents that are either very similar in character and quality or registers the same patent across multiple countries and jurisdictions. To avoid multiple counting of essentially the same invention, patents for the analysis below were grouped in families.³⁰⁶

Retrieval was limited to patents registered since January 1, 2015 when the quantum race began to gather momentum.³⁰⁷ The endpoint was December 31, 2021. Following the elimination of false positives, the total number of patent family records retrieved in the search process was 4,191. The output files of 4,191 patent family records (alongside their links to 10,000+ other patent records they cite as prior art) were then separated into “U.S.” (patents owned by entities headquartered in the United States) and “Chinese” (patents owned by entities headquartered in China) data for the purposes of statistical modeling.

Characteristics of the U.S.-China Patent Networks

What are some of the key insights that the analysis of the above dataset can generate? First, the figure below shows the top 10 organizations that registered patents in quantum computing and quantum communication between 2015 and 2021.

304 Martino Travagnin, “Patent Analysis of Selected Quantum Technologies,” JRC Technical Reports (Luxembourg: EU Publications Office, 2019). <https://data.europa.eu/doi/10.2760/938284>. Accessed April 9, 2025.

305 “Patent Families,” European Patent Office (undated). <https://www.epo.org/searching-for-patents/helpful-resources/first-time-here/patent-families.html>. Accessed March 21, 2025.

306 “Global Patent Index (GPI),” European Patent Office (undated). <https://www.epo.org/searching-for-patents/technical/espacenet/gpi.html>. Accessed March 21, 2025.

307 Martin Giles, “The U.S. and China Are in a Quantum Arms Race That Will Transform Warfare,” *MIT Technology Review* (January 3, 2019). <https://www.technologyreview.com/2019/01/03/137969/us-china-quantum-arms-race/>. Accessed April 9, 2025.

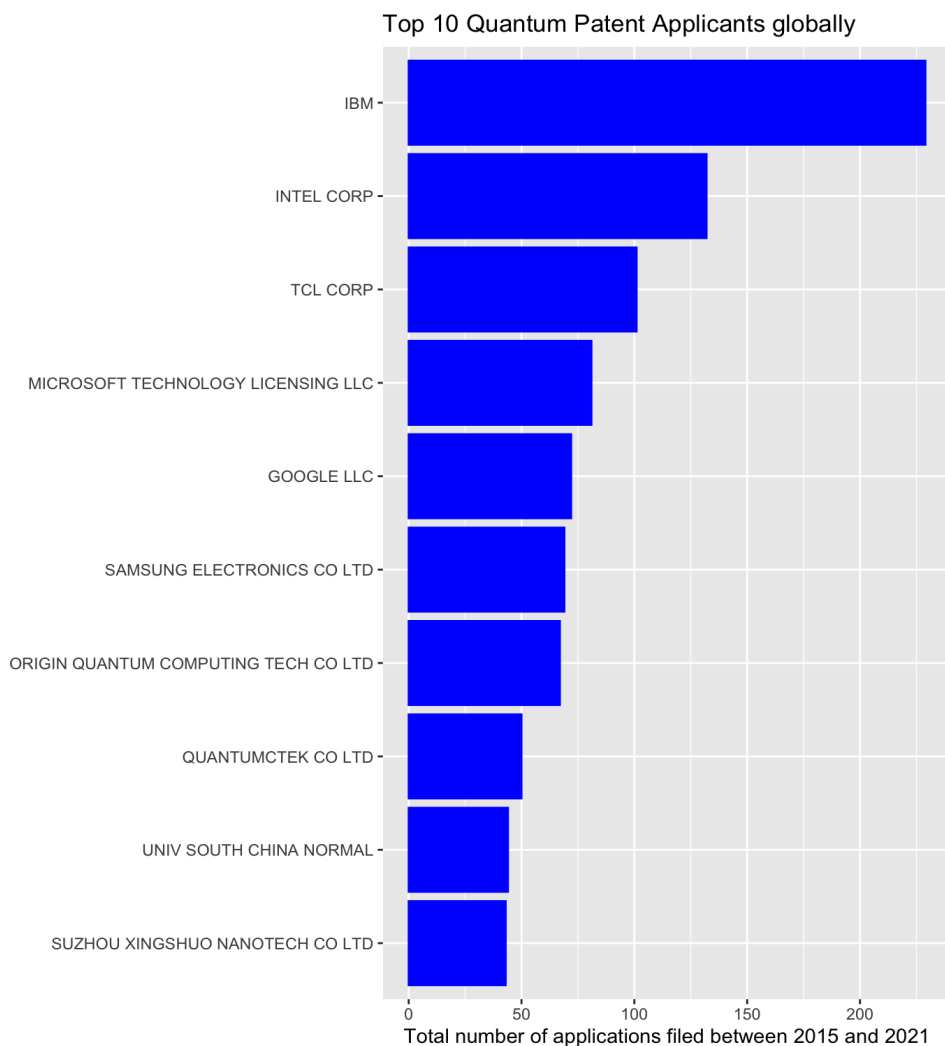


Figure 5: Cumulative quantum patent registrations by the top 10 registering entities, 2015-2021.

However, the dominance of American companies at the top of the chart does not imply an overall leadership position in patenting activity. Figure 6 shows the total number of patents registered by country for each year under consideration. While roughly on a par with the United States in 2015, China has come to dominate the patenting landscape and outperforms the U.S. by a magnitude of four in terms of annual patent registrations. While the big players are American, China has developed a large number of small to mid-sized entities that register quantum patents at significant pace. Over a five-year period, the number of annual patents owned by organizations headquartered in China has risen fivefold.

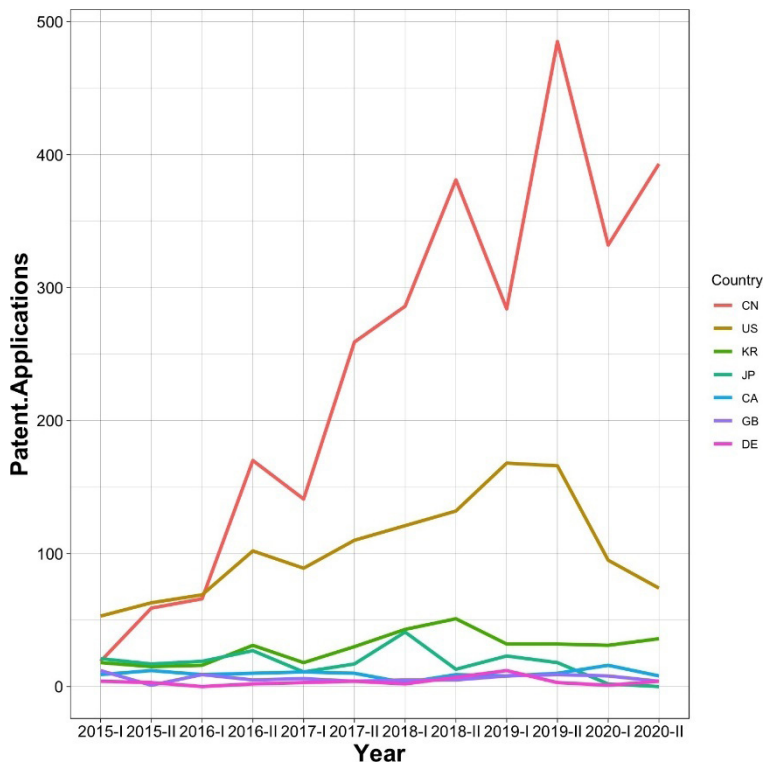


Figure 6: Quantum technology patent registrations in the top 5 countries.

Other countries trail by a significant margin. The patent output rate of Japan, Canada, the UK, and Germany has been fairly steady, however. The data suggest that China changed gears around 2015 and is now pursuing its quantum development program at full throttle.

More Than a Quantum of Preferential Treatment

Do American and Chinese patents recognize and engage with inventions of their strategic rival? Intuitively, the specter of an intensifying race over emerging technologies may be a disincentive to form collaborative ties with the competitor. In network-analytical terms, when new patents cite other inventions as prior art, where do edges point?

Each node (patent) in the quantum patent network can be considered as belonging to one of the following groups:

- I. **source:** patents registered by Chinese/U.S. institutions in the period under investigation. Nodes in “source” cite other patents but are not themselves cited by any other patent record in the dataset. Citations establish an outward edge between the patent and a node that is being cited (patent citation networks are directed graphs). As they cite other patents but are not cited by any other patent in the dataset, source nodes have only outgoing edges.
- II. **hubs:** new inventions may cite prior patents that serve as hubs. These are cited by new patents in the dataset but may themselves also cite other patents in the same set. For instance, a 2020 patent cites a 2018 patent which cites a 2016 patent, all of which are in the dataset that covers the period 2015-2021. Hubs therefore have in- as well as out-degrees, meaning that a chain of citations traverses through the hub.

III. sinks: such chains come to a stop when they cite sinks. Sinks are patents that are cited by other records in the dataset but themselves do not cite any other patents or prior art. Sink nodes therefore only have in-degrees.

Cited patents were labeled as either “domestic” or “foreign” in origin. In the hive plots below, nodes are grouped by their degree (i.e., the number of links they have with other nodes): the farther the distance to the core, the higher the degree of the node. Edges that point to domestic origins (i.e., a Chinese/U.S. patent cites another Chinese/U.S. patent as prior art) are colored in green. Citations of foreign-owned patents are colored in red.

The Chinese quantum patent citation network is made up of 6,134 nodes and 6,970 edges, with radii spanning from 1 to 27. This means that the smallest node in the network (closest to the core) only has one edge pointing either to or from it, while the biggest node (as furthest away from the center of the graph) connects to 27 other nodes (citations).

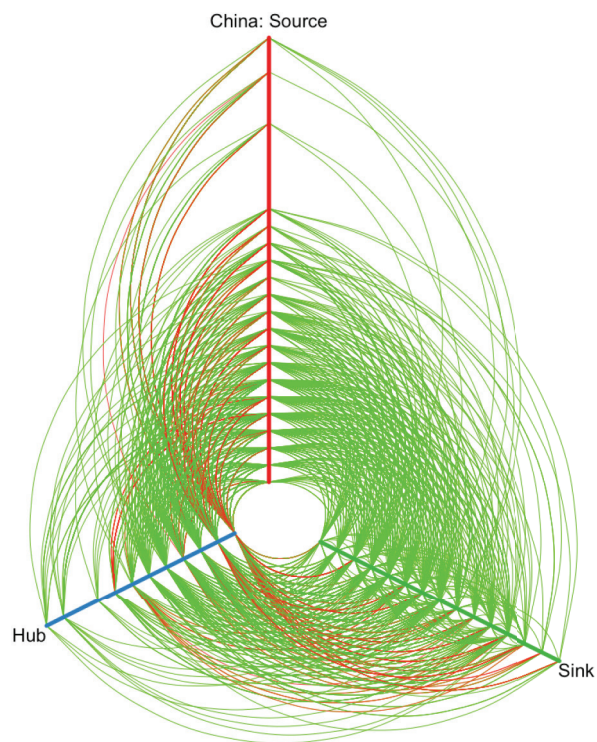


Figure 7: Hive plot of the Chinese quantum patent network with citation links to domestic prior art in green and foreign prior art in red.

Two observations stand out: (i) new Chinese quantum technology patents overwhelmingly cite domestic, i.e. Chinese-owned technology (green), and (ii) where new Chinese patents that are not being cited by any other entity (source), or cite patents that themselves do not cite any prior art (sink), these citation relationships are almost 100% domestic in character.

The American quantum patent network is significantly smaller. It is made up of 2,863 nodes and 3,201 edges, with radii spanning from 1 to 63.

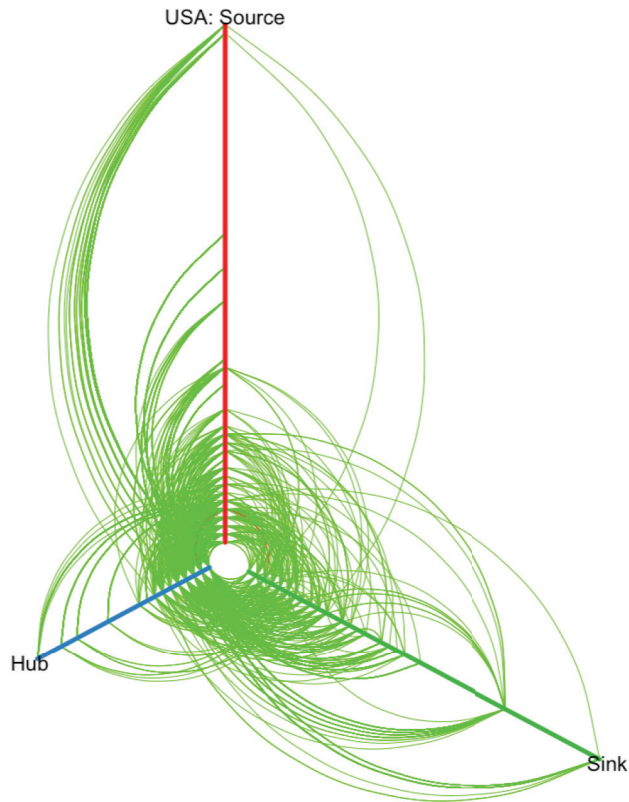


Figure 8: Hive plot of the U.S. quantum patent network with citation links to domestic prior art in green and foreign prior art in red.

As far as the U.S. is concerned, the phenomenon of exclusively citing domestic technologies is even more pronounced. Out of more than 3,000 edges (i.e., citation links) in the network, only 100 or so point to foreign technologies. These are mostly low-impact nodes around the core with only a couple of edges pointing to/from them and as such are hardly visible in the graph.

Some commentators suggest lax Chinese practices in recognizing foreign intellectual property.³⁰⁸ While the analysis points to a strong preference of Chinese entities to cite domestic technologies, this effect is even stronger in American data. Prior art not owned by U.S. entities finds no recognition in citation links. In both the United States and China, the development of quantum capabilities is siloed; non-domestic inventions are irrelevant to national quantum programs.³⁰⁹

308 Yukon Huang and Jeremy Smith, “China’s Record on Intellectual Property Rights Is Getting Better and Better,” *Foreign Policy* (October 16, 2019). <https://foreignpolicy.com/2019/10/16/china-intellectual-property-theft-progress/>. Accessed April 9, 2025.

309 Most patent databases provide machine translations of patent descriptions and specifications so that a lack of awareness of foreign activity due to language barriers, while they certainly exist, seems insufficient an explanation for the extreme preferential treatment of domestic sources.

Only a Handful of “Super Patents” Hold the Networks Together

A key question for policymakers is to ask what makes some patents more important than others. Computing the k -core of a network reveals the strongest nodes that hold up against sustained attacks on the periphery of the network.³¹⁰ The idea is to successively “peel away” outer nodes with only a few connections to reveal the core of the network that holds the entire graph together. The k -core is a token of resilience: how many shocks to its periphery can the core of the network survive? The core is the subnetwork of the most tightly interlinked nodes, the removal of which would cause the entire citation network to fold and collapse in on itself (i.e., return an empty graph with zero edges).³¹¹

In the absence of the benefit of hindsight that would allow for a more precise assessment of which patents will be successful, the k -core is a robust metric that measures the number of “important” (i.e., highly influential) patents that give their national quantum networks their characteristic shape.

Table 2: k -core statistics for the Chinese quantum patent network for $k = 1 \dots 5$.

k	1	2	3	4	5
# nodes	4,429	1,463	218	11	13

The Chinese network has a unique core for $k = 5$. After five steps, the algorithm terminates, yielding 13 patents at the very core of the network. The removal of these 13 nodes would collapse the graph—none of the thousands of patents in the network would be able to speak to any other. More than 4,400 nodes are removed after the first cut, pointing to substantial “debris” at the periphery of the graph. Only 13 patents out of more than 6,000 records survive and constitute the stable core of this citation network.

310 Mark Hoffman, *Methods for Network Analysis* (2021). https://bookdown.org/markhoff/social_network_analysis/. Accessed April 9, 2025. The concept assumes undirected graphs so for calculating the k -core the direction of citations does not matter. This assumption has no effect on the interpretation of the indicator.

311 Formally, the k -core of a network is the maximal subgraph such that its minimum degree is greater or equal to k .

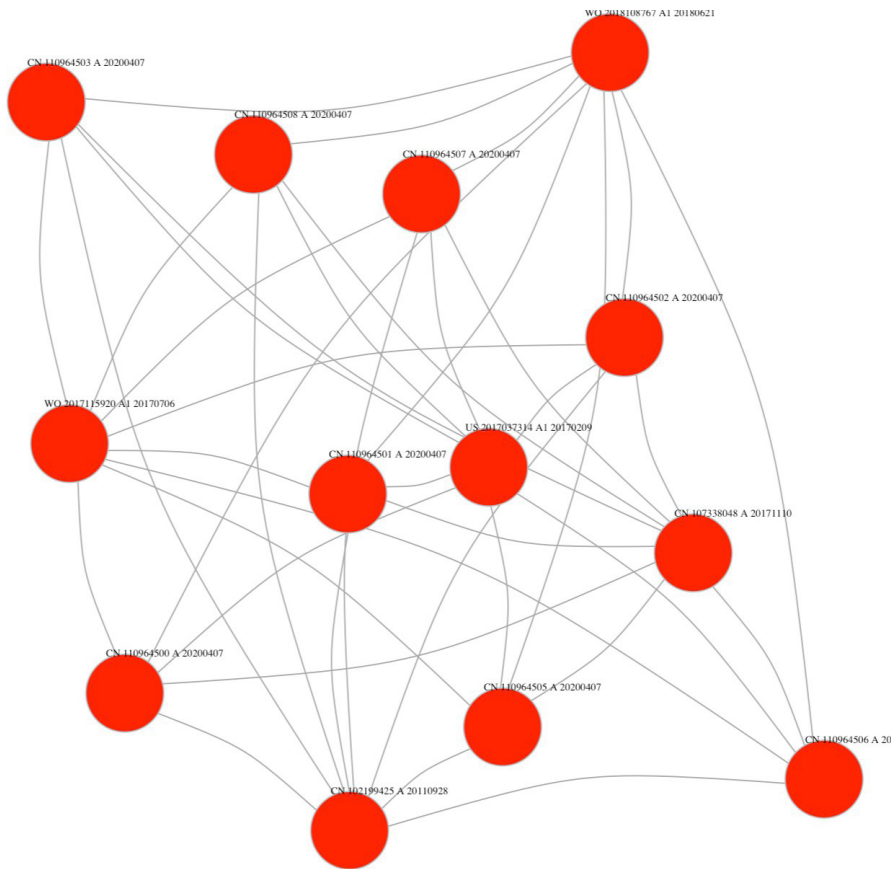


Figure 9: The stable 5-core of the Chinese quantum patent network.

As far as the United States is concerned, the maximum subgraph is reached for $k = 4$, suggesting that the U.S. citation network is less closely linked and less stable than the Chinese one. While the Chinese network loses around two thirds of its nodes after the first round, this effect is even more pronounced in the U.S. network where roughly three quarters of patents do not survive the first chop.

Table 3: k-core statistics for the U.S. quantum patent network for $k = 1...4$.

k	1	2	3	4
# nodes	2,215	520	110	18

The U.S. 4-core contains 18 nodes, i.e. five more than its Chinese counterpart.

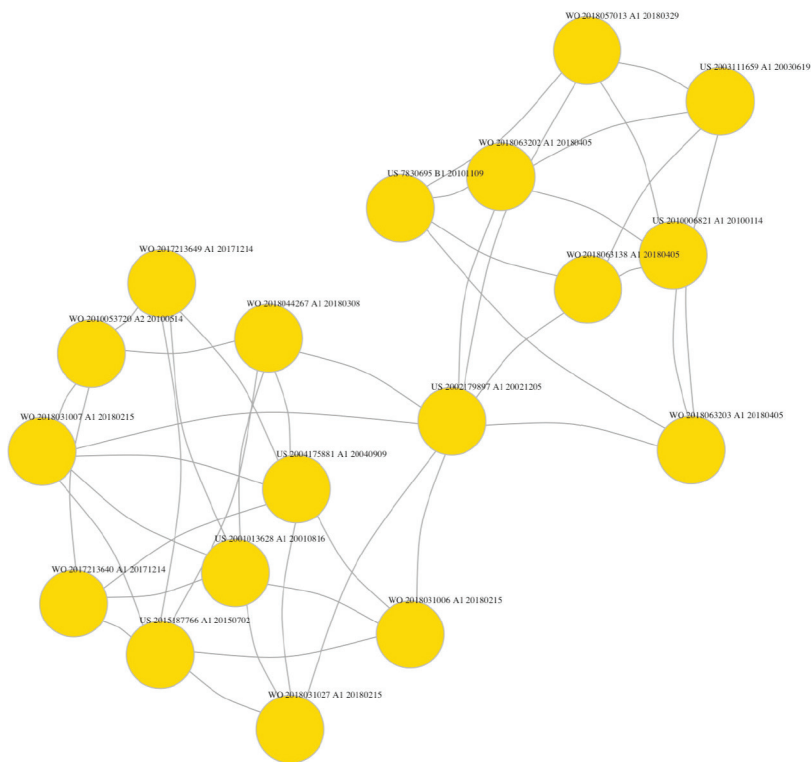


Figure 10: The stable 4-core of the U.S. quantum patent network.

Both the Chinese and U.S. quantum patent networks carry a large number of patents that do not seem very impactful (they cite only one patent, or are being cited only once), and are thus quickly removed by the k-core algorithm. What is more, neither side would cite the other, reflecting a pattern of “don’t cite the strategic rival.” While the Chinese network is larger, the two nations’ quantum ecosystems are structurally very similar.

These findings put into perspective alarmist concerns that the United States is losing the quantum technology race to China, ostensibly conceding precious technological advantage. Patenting activity in quantum technologies does not suggest the United States is on a losing trajectory. Both the U.S. and Chinese networks carry substantial deadweight; patents that are not being picked up. While the Chinese network is considerably larger, reflecting the rise in Chinese output, both ecosystems have produced a similar number of successful patents, suggesting parity rather than dominance between the two great powers in the domain of quantum technologies.

Policy Implications

The above analysis of 4,200 patent families in quantum technologies and the 10,000+ patents they cite as “prior art” suggests that, while roughly on a par with the United States in 2015, since then China has accelerated its quantum development program. While the biggest registering organizations

by number of filings are big U.S. corporations, China has developed a large number of small- to mid-sized firms that register quantum patents at pace. China changed gears around 2015 and is now pursuing its quantum development program at full throttle.

The case study finds significant preferential treatment of domestic technologies in both China and the United States. Chinese quantum patents overwhelmingly cite other Chinese-owned patents as prior art, and U.S. patenting activity is no different. Neither program seems to be taking much interest in its strategic rival.

Overall, quantum patenting activity seems to be following a trend observable in AI also. The top of the field is dominated by big U.S. corporations while China leads by count of registered AI patents overall. This is due to an extremely large number of smallish Chinese research institutes that register AI/ML patents at pace.³¹² This case study finds a similar dynamic in the quantum domain: the field is dominated by large U.S. corporations but in terms of numbers, China enjoys a competitive edge thanks to a large army of registering “foot soldiers.”

Both networks are driven by only a small number of influential patents. Computing the k-core has revealed that only a handful of highly successful patents hold the U.S. and Chinese networks together. On that count, the United States and China are doing equally well. The case study does not support the view circulating in the media that the U.S. is losing the quantum innovation race to China. While Chinese progress is indeed remarkable, it seems premature to be pessimistic about American technology leadership in the quantum domain. Simple patent counts, increasingly mobilized in press coverage of the quantum innovation race, paint a misleading picture of the true structural characteristics of this competition. The analysis above suggests parity rather than dominance.

Conclusion

The strategic analysis of patent data provides a lens through which emerging technologies and their implications for national and international security can be understood. By systematically examining patents in quantum technologies, this chapter has demonstrated how patent analysis serves as a valuable tool for monitoring technological advancement and assessing emerging capabilities, both at home and abroad. Patent data offer a unique advantage: unlike other intelligence sources, they are publicly accessible and contain detailed descriptions of technological innovations, making them a critical component of open source intelligence (OSINT) efforts.

One of the central findings of this chapter is the diversity of methodological approaches that can be applied to patent data. From traditional bibliometric analysis (which reveals citation patterns and identifies influential patents) to advanced network analytics and machine learning (which map the interconnectedness of innovation clusters), each approach provides a distinct perspective on the competitive landscape of emerging technologies.

The comparative case study of U.S.-China patenting activity in quantum technologies has underscored how patent data reflect broader strategic priorities. China is found to have given its

312 Roland Freist, “AI & Machine Learning: China, the U.S., and Japan in the Lead with AI Patents,” in *AI and Machine Learning* (Hanover: Hannover Messe, February 15, 2019), <https://www.hannovermesse.de/en/news/news-articles/china-the-us-and-japan-in-the-lead-with-ai-patents> (accessed April 9, 2025); Na Liu et al., “Mapping Technological Innovation Dynamics in Artificial Intelligence Domains: Evidence from a Global Patent Analysis,” *PLOS ONE* 16, no. 12 (December 31, 2021), <https://doi.org/10.1371/journal.pone.0262050> (accessed April 9, 2025).

quantum program a big push, attesting to a policy change in 2015 and concerted efforts in patenting quantum technologies since then. However, the case study has presented evidence against the widespread assertion that the United States is losing the quantum innovation race to China. The analysis of patent data suggests both nations see eye to eye in developing quantum capabilities. This should not make for a comforting read for U.S. policymakers, planners, and strategists, as the data also reflect the intense commitment China has made to growing its capabilities in this domain, making accelerating growth rates in the future likely.

As the pace of technological change increases, patent data will become an even more vital resource for understanding emerging capabilities and preparing for the geopolitical shifts they may bring. By integrating patent analytics into intelligence work and security studies, policymakers and analysts find a useful tool to anticipate and shape the future landscape of global technological power. As such, patent analysis can add substantially to the methodological toolkit for investigating CGSR's major research areas, especially its programs on Major Power Rivalry and Conflict as well as The Future of Long-Term Competitive Strategies to which deep insight into innovation dynamics is paramount.

Energy Technology Competition: Is the United States Keeping Pace?

*Asmeret Asghedom, Raymond Hughes, and Brandt Mabuni*³¹³

Introduction

There has been a considerable shift over the past decade in both the nature and focus of technology competition in the energy sector. It has become more competitive—with more players and less dominated by the West—and the focus has shifted to alternative energy technologies (like battery storage, renewables, and nuclear energy) from fossil fuels. The main players vary depending on the technology, but for the most part they include the United States, China, Russia, some European countries, South Korea, and Japan. The growing competitive landscape opens the opportunity to achieve leadership in potentially lucrative new energy options, along with the tangential diplomatic and political benefits that accompany establishing new, or reinvigorating old, energy partnerships.

In this chapter, we address the following questions: As technology competition in energy evolves, is the United States keeping pace with its rivals, China and Russia? What are the strategic advantages (technological, economic, and political) gained by the leader? After addressing these questions, we will provide a case study to illustrate how energy competition is unfolding to develop an entirely new source of energy—nuclear fusion.

While the United States continues to be the world's largest producer of both oil and gas and among the world's top three oil and gas exporters, it has fallen behind in the exports of nuclear, renewable, and battery storage technologies. This is problematic as global demand for these technologies is growing. The United States was the original pioneer of nuclear, renewable, and battery storage technologies because of its competitive edge in science research and innovation. However, China currently leads global exports of renewable energy and battery storage technologies, and Russia leads global exports of nuclear reactors and fuel. Consequently, the United States and its allies have become dependent on China for most renewable and battery storage technologies and Russia for nuclear fuel. Thus, at the end of the chapter, we will conclude with recommendations for how U.S. decisionmakers can help the U.S. private sector maintain a leadership role in new energy technologies if they achieve noteworthy breakthroughs that help them to reclaim that role.

Technology competition in energy can span a spectrum of activities—basic research, development, demonstration, reaching economic viability and commercialization, domestic deployment, and international exports. While this spectrum is highlighted in this chapter, most of the focus is on the latter stages of commercialization, deployment, and international exports. Leading in these stages can help a country gain key strategic advantages on the global stage.

Brief Overview: Evolution of Energy Technology Competition

The United States trumps its competitors in basic research and innovation of energy technologies. Key inventions and discoveries in nuclear energy, solar photovoltaics, lithium-ion battery chemistry,

313 The authors are grateful to Dr. Joshua Massey of the University of Georgia for his feedback on a draft of this paper.

oil and gas drilling (like 3D seismic imaging, directional drilling, and hydraulic fracturing), and large-scale liquefaction were made in the United States.³¹⁴ According to the International Energy Agency (IEA), “the United States has created the ground for many of the energy transition patents available today.”³¹⁵

However, U.S. competitors have gained access to U.S. methods and technologies over time through the licensing of technologies, publication of scientific and technical articles, conference presentations, diffusion of technologies, industrial espionage, and in the case of China, forced technology transfers.³¹⁶ Over time, China and Russia³¹⁷ have proven better at cost-competitive manufacturing and deployment of energy technologies, which is key to leading technology commercialization, mostly thanks to massive government subsidies. The only exception is the oil and gas industries, where the United States and other Western companies still play a leading role worldwide.

Nuclear Energy

The United States was the first country to bring online a commercial nuclear power plant in the late 1950s.³¹⁸ From the 1960s to 1980s, the United States cemented its role as the top innovator and exporter of nuclear energy technologies by significantly increasing its domestic capacity of nuclear energy and providing the world with nuclear supplies and manufacturing expertise.³¹⁹ However, even prior to the high-profile accidents of Three Mile Island in 1979 and Chernobyl in 1986, American and European engineering firms had begun shifting away from nuclear power. Not only had public opinion

314 Paul Dabbar, *U.S. Energy Superpower Status and a New U.S. Energy Diplomacy*, Hoover Institution (February 13, 2024), https://www.hoover.org/sites/default/files/research/docs/Dabbar_WebreadyPDF.pdf. Accessed December 19, 2024); Shea, “The History of the LNG Industry,” <https://www.sheaws.com/the-history-of-the-lng-industry/> Accessed December 19, 2024.

315 International Energy Agency, “United States 2024: Energy Policy Review” (2024). <https://iea.blob.core.windows.net/assets/b5826832-7182-4abe-9041-01c9f00d69d/UnitedStates2024.pdf>. Accessed December 19, 2024.

316 For example, in China, “Battery Manufacturers Used Licensing and Acquisitions to Gain Access to Foreign Technology.” See Anders Hove, *Clean energy innovation in China: fact and fiction, and implications for the future*, The Oxford Institute for Energy Studies (July 2024), pp. 17-18, <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/07/CE14-Clean-energy-innovation-in-China-Final.pdf>. Accessed December 19, 2024. For more information on China’s forced technology transfers and industrial espionage in the wind industry, see Joseph Webster, “China’s Wind Industrial Policy ‘Succeeded’ – But at What Cost?” Atlantic Council (May 1, 2023). <https://www.atlanticcouncil.org/blogs/energysource/chinas-wind-industrial-policy-succeeded-but-at-what-cost/>. Accessed December 19, 2024. For more on Russian espionage into the U.S. nuclear program in the 1940s, see “Espionage and the Manhattan Project (1940-1945),” U.S. Department of Energy, <https://www.osti.gov/opennet/manhattan-project-history/Events/1942-1945/espionage.htm>. Accessed December 19, 2024.

317 Russia has made some noteworthy improvements to nuclear energy. For example, Russian engineers developed a relatively cheaper and less energy intensive method of enriching uranium than the method used by American and French engineers. See Marco Siddi and Kristiina Silvan, “Nuclear Energy and International Relations: The External Strategy of Russia’s Rosatom,” *International Politics* (October 2024). <https://link.springer.com/article/10.1057/s41311-024-00618-0>. Accessed December 19, 2024.

318 U.S. Energy Information Administration, “Nuclear Energy Explained” (August 2023). <https://www.eia.gov/energyexplained/nuclear/us-nuclear-industry.php>. Accessed December 19, 2024.

319 Suzanna Hobbs Baker, et al., “Getting Back in the Game: A Strategy to Boost American Nuclear Exports,” *Third Way* (January 10, 2017). <https://www.thirdway.org/report/getting-back-in-the-game-a-strategy-to-boost-american-nuclear-exports>. Accessed December 19, 2024.

soured, but the industry was growing unwieldy under onerous regulatory conditions, surging project costs, and cheap fossil fuels.³²⁰

Starting around 2007, Russia began its ascent as a leader of reactor and nuclear fuel exports owing to the consolidation of the Soviet nuclear enterprise to a unified state corporation named Rosatom, a new reactor design,³²¹ expedited licensing timelines,³²² preferential financing terms (backed by government loans) for plants built abroad, and eventually the “all-inclusive packages for new nuclear plants—covering the cost of constructing the reactor, training employees, and even operating the facility.”³²³

Russia currently holds 70% of the global nuclear reactor market,³²⁴ and as of 2020, it provided 46% of global uranium enrichment capacity and 38% of global uranium conversion capacity utilization.³²⁵ The United States is struggling to compete with Russia on nuclear technology exports. For example, as of the beginning of 2022, Russia had 13 exported reactors under construction abroad, while China had one and the United States had none.³²⁶ But the U.S. government and U.S. companies working on small modular reactors (SMRs) are hoping their advancements will yield the United States more market share in the near future.

Though China’s international experience is currently limited to reactors completed in Pakistan, an extraordinary domestic buildout is showcasing China’s ability to deliver nuclear power on budget and faster than any other country.³²⁷ Over 30 reactors are currently under construction or approved to be constructed, and state-backed developers believe Beijing could approve 10 more each year through 2035.³²⁸ Observers anticipate China’s enormous nuclear-building capacity will turn to exports in the

320 Frank Bosch, “Taming Nuclear Power: The Accident near Harrisburg and the Change in West German and International Nuclear Policy in the 1970s and early 1980s,” *German History* 35, no. 1, (2017), p. 71. <https://doi.org/10.1093/gerhis/ghw143>.

321 Steve Thomas, “Russia’s Nuclear Export Programme,” *Energy Policy* 121 (2018). <https://doi.org/10.1016/j.enpol.2018.06.036>. Accessed December 19, 2024.

322 Kyle Sallee, “Regaining American Competitiveness in the Global Nuclear Power Market,” American University (February 5, 2021). <https://www.american.edu/sis/centers/security-technology/regaining-american-competitiveness-in-the-global-nuclear-power-market.cfm>. Accessed December 19, 2024.

323 Suzanna Hobbs Baker, et al., “Getting Back in the Game: A Strategy to Boost American Nuclear Exports,” Third Way (January 10, 2017). <https://www.thirdway.org/report/getting-back-in-the-game-a-strategy-to-boost-american-nuclear-exports>. Accessed December 19, 2024.

324 Alexandra Prokopenko, “Rosatom: A Difficult Target,” German Council on Foreign Relations (May 9, 2023). <https://dgap.org/en/research/publications/rosatom-difficult-target>. Accessed December 19, 2024.

325 Asmeret Asghedom, *Examining the Energy Transition through the Lens of Great Power Competition*, Center for Global Security Research (August 2023). <https://cgsr.llnl.gov/sites/cgsr/files/pubs/2024-08/CGSR-Livermore-Paper-12-EnergyTransition-2023.0831.pdf>. Accessed December 19, 2024.

326 Matt Bowen and Alec Apostoaei, *Comparing Government Financing of Reactor Exports: Considerations for U.S. Policy Makers*, Columbia’s Center on Global Energy Policy (August 25, 2022). https://www.energypolicy.columbia.edu/wp-content/uploads/2022/08/NuclearFinance-CGEP_Report_111022-1.pdf. Accessed December 19, 2024.

327 “China is building nuclear reactors faster than any other country,” *The Economist* (November 30, 2023). <https://www.economist.com/china/2023/11/30/china-is-building-nuclear-reactors-faster-than-any-other-country>. Accessed December 16, 2024.

328 Dan Murtaugh, “China’s Nuclear Energy Expansion is Getting Even Faster,” *Bloomberg* (March 15, 2024). <https://www.bloomberg.com/news/newsletters/2024-03-15/china-s-nuclear-energy-expansion-is-getting-even-faster>. Accessed December 16, 2024.

future, following the “dual circulation” strategy seen with electric vehicles (EVs) and batteries.³²⁹ The long-term, high-value nature of nuclear power projects also make them uniquely suited for integration with China’s Belt and Road Initiative or other strategic aims.³³⁰

Renewable Energy and Battery Technologies

For the United States, the story of renewable and associated technologies, specifically solar and battery technologies, has become similar to nuclear energy—with the United States initially leading innovation, but eventually being eclipsed by a rival as a global supplier. In 1883, Charles Fritts, an American inventor, created the world’s first solar panel prototype,³³¹ and in 1954, U.S.-based Bell Laboratories developed the world’s first commercial solar cells.³³² Despite noteworthy technological advancements in solar energy made by American scientists, solar deployments did not begin to take off in the United States until after the passage of the 2009 stimulus package under the Obama administration.³³³

In China, however, solar manufacturing and deployments began to rise in the 1990s as solar energy was seen as a way to diversify the country’s energy consumption, which was heavily dependent on foreign imports of fossil fuels.³³⁴ Coincidentally, in the late 1990s, Germany began providing capital, technology, and expertise to help boost China’s manufacturing of solar panels for the German market.³³⁵ Chinese solar startups used licensed technology, acquired manufacturing and production equipment and training from both Germany and Japan and engaged in international collaborations with countries in Europe and Asia.³³⁶ Like Germany, other European governments began providing domestic subsidies to buy and install solar panels around this time, opening up a large export market for Chinese solar panels.³³⁷ Decades later, Chinese companies now control more

329 Stephen Ezell, "How Innovative is China in Nuclear Power?", Information Technology & Innovation Foundation Hamilton Center on Industrial Strategy" (June 2024), p. 3. <https://itif.org/publications/2024/06/17/how-innovative-is-china-in-nuclear-power/>. Accessed December 16, 2024.

330 Lami Kim, “Nuclear Belt and Road and U.S.-South Korea Nuclear Cooperation,” Center for Strategic and International Studies (April 24, 2023). <https://www.csis.org/analysis/nuclear-belt-and-road-and-us-south-korea-nuclear-cooperation>. Accessed December 16, 2024.

331 “Who Invented Solar Panels? Uncover Solar Energy’s Origins,” Anker Solar (November 2024). <https://www.anker.com/blogs/solar/who-invented-solar-panels>. Accessed December 19, 2024.

332 Ibid.

333 Jim Noden, “A Brief History of Solar Energy in the U.S.,” BrightEye Solar (April 2017). <https://brihteyesolar.com/brief-history-solar-energy-us/>. Accessed December 19, 2024.

334 Ben McWilliams, et al., “Smarter European Union industrial policy for solar panels,” Bruegel (February 2024). <https://www.bruegel.org/policy-brief/smarter-european-union-industrial-policy-solar-panels>. Accessed December 19, 2024.

335 John Fialka, “Why China Is Dominating the Solar Industry,” *Scientific American* (December 19, 2016). <https://www.scientificamerican.com/article/why-china-is-dominating-the-solar-industry/>. Accessed December 19, 2024.

336 Anders Hove, “Clean Energy Innovation in China: Fact and Fiction, and Implications for the Future,” p. 17.

337 Keith Bradsher, “How China Came to Dominate the World in Solar Energy,” *The New York Times* (March 8, 2024). <https://www.nytimes.com/2024/03/07/business/china-solar-energy-exports.html>. Accessed December 19, 2024.

than 80% of the solar panel supply chain globally, owing to cheaper production costs (lower labor and electricity costs) and government support in various forms.³³⁸

Innovation of the modern-day lithium-ion battery also originated in the United States. The first iteration of the rechargeable lithium-ion battery was invented at U.S.-based Exxon by an English scientist Michael Stanley Whittingham in 1972.³³⁹ Exxon eventually licensed the technology to three companies in Asia, Europe, and the United States, overlooking the future value and utility of the invention. Scientific writings about lithium-ion batteries eventually inspired chemists at Asahi Chemical in Japan in the 1980s, who made important modifications and began sharing crude prototypes with Sony in Japan. Eventually, Sony developed the first commercially rechargeable lithium-ion battery in 1991.³⁴⁰

Despite the innovative roots of lithium-ion batteries starting outside of China, it has eventually become the largest manufacturer of lithium-ion battery cells, while also owning a majority of the global battery supply chain including the extraction and refining of battery minerals (like graphite, lithium, and nickel) and the production of the battery cathode and anode.³⁴¹ Like solar and wind, China has benefited from forced technology transfers from foreign companies that set up manufacturing facilities and joint ventures in China to meet local content requirements for EVs and EV battery production.³⁴²

The evolution of wind energy technology development and deployment is following a similar trajectory. European innovators and companies have traditionally led advancements in wind energy technologies worldwide (from innovation, design, manufacturing, and installation) since the world's first known wind turbine produced electricity in Scotland in 1887.³⁴³ Chinese companies did not start manufacturing and installing wind turbines until about a century later.

Chinese companies obtained wind technology mainly from European companies via technology transfers after foreign equipment manufacturers established manufacturing centers and joint ventures in China to meet local content requirements.³⁴⁴ Chinese companies have since collectively become the world's largest manufacturers of wind turbines, owing to its large domestic market.³⁴⁵ These Chinese

338 You Xiaoying, "The 'New Three': How China Came to Lead Solar Cell, Lithium Battery and EV Manufacturing," *Dialogue Earth* (November 7, 2023), <https://dialogue.earth/en/business/new-three-china-solar-cell-lithium-battery-ev/> (accessed December 19, 2024); International Energy Agency, "China currently dominates global solar PV supply chains," (August 2022), <https://www.iea.org/reports/solar-pv-global-supply-chains/executive-summary> (accessed December 19, 2024).

339 "John B. Goodenough - The Inventor of the Li-ion Battery," *Fuergy* (2018). <https://www.fuergy.com/blog/john-b-goodenough-the-inventor-of-the-li-ion-battery>. Accessed December 19, 2024.

340 For more, see Charles Murray, "Who Really Invented the Rechargeable Lithium-Ion Battery," *IEEE Spectrum* (July 2023). <https://spectrum.ieee.org/lithium-ion-battery-2662487214>. Accessed December 19, 2024.

341 Asmeret Asghedom, "Examining the Energy Transition through the Lens of Great Power Competition," p. 30.

342 Anders Hove, "Clean energy innovation in China: fact and fiction, and implications for the future," p. 18.

343 Zachary Shahan, "History of wind turbines," *Renewable Energy World* (November 2014). <https://www.renewableenergyworld.com/wind-power/history-of-wind-turbines/>. Accessed December 19, 2024.

344 Anders Hove, "Clean energy innovation in China: fact and fiction, and implications for the future," p. 17.

345 Global Wind Energy Council, "Wind Turbine Manufacturers See Record Year Driven by Growth in Home Markets" (May 2024). <https://gwec.net/wind-turbine-manufacturers-see-record-year-driven-by-growth-in-home-markets/>. Accessed December 19, 2024.

companies are starting to expand foreign exports and install wind components overseas, which has caused concern among European companies on whether they can compete with China.³⁴⁶

The United States' inability to gain and/or maintain a commercial lead on energy technologies like nuclear and renewable technologies, despite innovative advancements, highlights the "innovation fallacy," as termed by Dr. Jeffrey Ding. According to Ding, "it matters less which country first introduces a major innovation and more which countries adopt and spread those innovations."³⁴⁷ While the United States has excelled at innovating energy technologies over the past decades, it has fallen behind with diffusing those technologies either domestically and/or internationally compared with China and Russia. China's rapid adoption of nuclear and renewable energy technologies, coupled with state support, boosted its manufacturing capacity and economies of scale, resulting in the production of relatively cheaper supplies for its domestic and international markets.

Why is the United States Struggling to Compete?

Despite the United States' frontier innovations in nuclear, renewable, and battery storage technologies, China and Russia's competitive approaches have made it difficult for U.S. companies to become leading global suppliers of these technologies. China and Russia have similar competitive strategies—both are centralized and state driven, utilize state-owned companies or private companies with close ties to the government, and leverage government subsidies and support. Given China's greater economic wealth, it is more aggressively pursuing efforts to develop and deploy an array of energy technologies compared with Russia.

China's Competitive Approach

The features defining China's competitive approach to energy technologies include:

- Centralized government planning targeting the development of certain technologies and supply chains (e.g., investing in mining domestically and abroad to extract mineral inputs for renewable and nuclear energy technologies)³⁴⁸
- Government subsidies toward research and development of renewable and nuclear technolo-

346 For example, "Chinese turbine prices are at least 20% lower than European and U.S. manufacturers." See Christopher Cytera and Oona Lagercrantz, "China Threatens Europe's Windmills," Center for European Policy Analysis (October 17, 2024). <https://cepa.org/article/china-threatens-europes-windmills/>. Accessed December 30, 2024.

347 Jeffrey Ding, "The Innovation Fallacy," *Foreign Affairs* (August 19, 2024). <https://www.foreignaffairs.com/china/innovation-fallacy-artificial-intelligence>. Accessed February 4, 2025.

348 China has released national strategies for the past couple decades stating priorities in technological development in nuclear energy, renewable energy technologies, energy storage, transmission and distribution lines, and electric vehicles. These include: 2006 The National Medium- and Long-Term Program for Science and Technology, China's 2016 National Innovation Development Strategy, the 2015 "Made in China 2025" strategy, and China's five-year plans, with the most recent 14th Five-Year Plan (2021-2025). See Asmeret Asghedom, "Examining the Energy Transition through the Lens of Great Power Competition," pp. 60-63.

gies³⁴⁹ and subsidies, tax breaks, and low-interest loans for state-owned companies³⁵⁰

- Obtaining access to foreign technologies and equipment through forced technology transfers, joint ventures, and local content requirements³⁵¹
- Government policies to stimulate domestic demand (i.e., feed-in tariffs, renewable energy targets, and mandates)³⁵² and support for Chinese-owned companies to scale-up manufacturing
- Ramping exports to international markets using excess manufacturing capacity, especially as domestic demand growth slows or plateaus³⁵³
- Engaging in the financing, investing, and construction of energy projects abroad by Chinese state-backed banks and companies³⁵⁴

349 National Renewable Energy Laboratory, “Renewable Energy in China,” (April 2004). <https://www.nrel.gov/docs/fy04osti/36045.pdf>. Accessed December 19, 2024.

350 China provides a significant amount of industrial subsidies to boost their strategic industries. For example, China is estimated to have provided \$237 billion in 2019 toward industrial subsidies in total. See Nik Martin, “From solar to EVs: How China is overproducing green tech,” DW (April 2024), <https://www.dw.com/en/from-solar-to-evs-how-china-is-overproducing-green-tech/a-68782157> (accessed December 19, 2024). For electric vehicles (EVs), China provided \$29 billion from 2009 to 2022 in subsidies and tax breaks to assist Chinese EV companies. See Zeyi Yang, “How Did China Come to Dominate the World of Electric Cars?” *MIT Technology Review* (February 2023), <https://www.technologyreview.com/2023/02/21/1068880/how-did-china-dominate-electric-cars-policy/#:~:text=When%20did%20China%20start%20investing,slice%20of%20the%20auto%20industry> (accessed December 19, 2024). Another source estimates that the Chinese government provided between \$60 billion to \$100 billion over the past decade to support its EV industry and its companies building out lithium mining and refining infrastructure needed for lithium-ion batteries. See One Charge, “How China Came to Dominate the Market for Lithium Batteries and Why the U.S. Cannot Copy Their Model” (January 2022), <https://www.onecharge.biz/blog/how-china-came-to-dominate-the-market-for-lithium-batteries-and-why-the-u-s-cannot-copy-their-model/> (accessed December 19, 2024). China even provides subsidies to its private sector companies, which often have connections to the state. For example, the government provided JinkoSolar \$165 million in subsidies in 2023 alone. See Andrew Rechenberg, “China’s Solar Firms Are Surviving on CCP Subsidies,” CPA (April 2024), <https://prosperousamerica.org/chinas-solar-firms-are-surviving-on-ccp-subsidies/> (accessed December 19, 2024).

351 Sean O’Connor, How Chinese Companies Facilitate Technology Transfer from the United States, U.S.-China Economic and Security Review Commission (May 2019). <https://www.uscc.gov/sites/default/files/Research/How%20Chinese%20Companies%20Facilitate%20Tech%20Transfer%20from%20the%20US.pdf>. Accessed December 13, 2024.

352 For example, in 2007, China released its Medium- and Long-Term Development Plan for Renewable Energy, announcing goals to increase the share of renewable energy (hydro, solar, wind, biomass, and biofuels) in total primary energy consumption to 10% by 2010 and 15% by 2020. For more information, see Asia Pacific Energy Portal, *Medium- and Long-Term Development Plan for Renewable Energy* (2007), <https://policy.asiapacificenergy.org/node/42> (accessed December 19, 2024). China has met these goals, with the share of renewable energy (including hydro) in total primary energy consumption reaching nearly 28% in 2023. See Statista, “Primary Energy Consumption in China from 2018 to 2023, by Fuel,” (2024), <https://www.statista.com/statistics/265612/primary-energy-consumption-in-china-by-fuel-type-in-oil-equivalent/#:~:text=Primary%20energy%20consumption%20in%20China%202018%2D2023%2C%20by%20fuel&text=Coal%20is%20by%20far%20the,exajoules%20in%20the%20previous%20year> (accessed December 19, 2024).

353 For example, “signs of excess solar and wind manufacturing capacity in China first emerged in 2009 and persisted through 2012, causing two of China’s largest solar firms at the time to file for bankruptcy and eventually prompting the deputy director general of the New Energy Department of China’s National Energy Administration to call for more Chinese financing toward renewable energy projects abroad.” See Asghedom, “Examining the Energy Transition through the Lens of Great Power Competition,” p. 59.

354 For example, “From 2007 to 2016, China’s two main policy banks, China Exim Bank and CDB, issued energy loans equivalent to the combined amount lent out by major Western-backed multilateral banks, which was \$196.7 billion.” For more on Chinese financing and investments abroad in energy projects, see Asghedom, “Examining the Energy Transition through the Lens of Great Power Competition,” pp. 34-54.

- Launching diplomatic initiatives to stimulate overseas investments, notably the Belt and Road Initiative³⁵⁵

China’s competitive edge is in manufacturing, low production costs, access to an array of raw materials (including critical minerals), and the control of supply chains, which bodes well for renewable and battery storage technologies as they have large supply chains and manufacturing requirements. Much of this is supported by Chinese government subsidies, tax breaks, cheap loans from China’s state-run banks, government-backed investment funds, “cheap land from local authorities to set up factories, cheap steel from state-owned mills[,] and cheap energy [especially coal-fired electricity] from state-owned utility companies.”³⁵⁶

China also has a competitive edge in the deployment, installation, and exports of renewable and associated technologies abroad (including solar, wind, hydro, batteries, and EVs) due to its ability to scale-up manufacturing quickly, take on large construction projects, finance energy projects overseas, and sell the technologies at a much lower cost.³⁵⁷ Thus, the United States, along with other countries, are struggling to compete with China on the manufacturing of renewable and associated technologies, given the cheap Chinese products flooding global markets, which is undermining investments in the United States and elsewhere.³⁵⁸

Chinese-state owned companies feature prominently in its approach to competition along with industrial polices. For example, the Chinese nuclear power sector runs on a backbone of two state-owned giants—China General Nuclear Power Group (CGN) and China National Nuclear Corporation (CNNC)—supported by a near-entirely domestic supplier ecosystem atop a lattice of strong industrial policies like the “Made in China 2025 Initiative.”

China’s main motivation in becoming a leading developer and exporter of energy technologies in part is the significant economic benefits. For instance, Chinese exports of solar panels, lithium-ion batteries, and EVs climbed from \$20 billion in 2017 to \$150 billion in 2023, making up 4.5% of China’s total exports.³⁵⁹ According to industry experts, “The ‘new trio’ of industries has replaced an ‘old trio’ of clothing, furniture, and appliances, not only becoming pivotal in shaping China’s economy but

355 For example, “Energy projects have been a major focus of BRI. Since BRI’s inception in 2013 to 2022, energy projects made up the largest share of total BRI investment and construction projects at about 40%.” Asmeret Ashgedom, “Examining the Energy Transition through the Lens of Great Power Competition,” p. 36.

356 Joseph Quinlan and Lauren Sanfilippo, “China Is Leading the World on Manufacturing, But the Race Isn’t Over,” *Barron’s* (August 2022). <https://www.barrons.com/articles/china-manufacturing-semiconductor-electronics-us-competition-51661894538>. Accessed December 19, 2024.

357 For example, “A module made in China is 50% cheaper than that produced in Europe and 65% cheaper than the US, according to the report.” See Wood Mackenzie, “China to hold over 80% of global solar manufacturing capacity from 2023-26,” (November 2023). <https://www.woodmac.com/press-releases/china-dominance-on-global-solar-supply-chain/>. Accessed December 19, 2024.

358 Christopher Casey, *Circumvention Inquiry into Solar Imports*, Congressional Research Service, IN11946 (May 2023). <https://crsreports.congress.gov/product/pdf/IN/IN11946/7>. Accessed December 19, 2024.

359 Jing Zhang and Christoph Nedopil, “China’s ‘new three’ exports dominate the 2023 global green transition,” Griffith University (April 2024). <https://blogs.griffith.edu.au/asiainsights/china-green-trade-report-2023/>. Accessed December 19, 2024.

also playing a crucial role in driving the country's exports to unprecedented heights."³⁶⁰ China is also motivated to develop various energy technologies to diversify its domestic energy sources, reduce its reliance on energy imports, and thereby, improve its energy security.

Russia's Competitive Approach

Similarly, the Russian government reaps sizable economic and energy security benefits from its support to its energy producers. Its largest source of state revenue is from oil and gas exports, accounting for 30% of Russia's federal budget in 2024.³⁶¹ Its exports of nuclear fuel amounted to \$3.1 billion in 2023, up from \$1.6 billion in 2021.³⁶²

The features defining Russia's competitive approach to energy technologies include:

- State-owned companies such as Rosatom (nuclear energy), Rosneft (oil), and Gazprom (gas), and private company Novatek (LNG) receive government support in the form of subsidies and tax breaks.³⁶³
- For nuclear reactor exports, Rosatom offers an "all-exclusive package" including competitive financing terms such as large loan amounts (backed by government subsidies), equity financing, lower interest rates, and a generous repayment period³⁶⁴ along with the full fuel cycle services to customers.³⁶⁵
- Rosatom also offers the "Build-Own-Operate" model to customers, where Rosatom "retains ownership and operations of the plant, taking on all financial, construction, and operational risks in exchange for a repayment plan based on future electricity revenues."³⁶⁶

360 "China's Top 10 Exports," China 2 Services LTD (April 2024). <https://www.china2west.com/chinas-top-10-exports-2024/>. Accessed December 19, 2024.

361 Vitaly Yermakov, "Fiscal Flex: Russia's Oil and Gas Revenues in 2024," Oxford Institute for Energy Studies (February 2025). <https://www.oxfordenergy.org/wpcms/wp-content/uploads/2025/02/Comment-Fiscal-Flex.pdf>. Accessed June 26, 2025.

362 Jeevan Vasagar, "Russia is Earning Billions Selling Nuclear Fuel to the West," Sense Maker Daily (April 2024). <https://www.tortoisemedia.com/2024/04/16/russia-is-earning-billions-selling-nuclear-fuel-to-the-west/#:~:text=Russia's%20total%20nuclear%20exports%20grew,to%20%24900%20million%20last%20year>. Accessed December 19, 2024.

363 Atle Staalesen, "Moscow Offers New Subsidies for Arctic Hydrogen," The Barents Observer (April 2023). <https://www.thebarentsobserver.com/new-energy/moscow-offers-new-subsidies-for-arctic-hydrogen/271895>. Accessed December 19, 2024.

364 Matt Bowen and Alec Apostoaei, "Comparing Government Financing of Reactor Exports: Considerations for US Policy Makers," pp. 13-15.

365 "The strength of Rosatom's export strategy for reactors and whole NPPs lies in its ability to provide all-inclusive packages comprising plant construction knowhow, training, support related to safety, non-proliferation regime requirements, flexible financing options (including Russian government loans) and handling of spent nuclear fuel." See Marco Siddi and Kristiina Silvan, "Nuclear Energy and International Relations: The External Strategy of Russia's Rosatom," p. 12.

366 Cindy Vestergaard, "Disruption and the Nuclear Industry," Stimson Center (September 2024). <https://www.stimson.org/2024/disruption-and-the-nuclear-industry/>. Accessed December 19, 2024.

The U.S. Competitive Approach: Adapting to the New Environment

While the U.S. energy industry continues to be largely driven by the private sector, the U.S. government has been increasing its role to counter Russia and China's state-led approaches. Since 2021, the U.S. government increased the available monetary support to stimulate research, development, and deployment of energy technologies among U.S. private sector companies.

An area where the U.S. government is taking a more proactive approach in energy technology competition is the development of advanced small modular reactors (SMRs), which are advanced reactors (Generation III+ and Generation IV)³⁶⁷ with a power capacity of 300 megawatts-electric (MWe) or less.³⁶⁸ The option of smaller-sized reactors allows for new avenues of application for nuclear power such as data centers, maritime shipping, remote communities, or off-grid industrial operations.³⁶⁹ In a bid to boost the SMR development pipeline and build up a domestic orderbook, in 2024, the U.S. government designated \$900 million in funds to assist "first movers" and "fast followers" in the Generation III+ SMR space with deploying their initial plants.³⁷⁰

The United States is also mounting a substantial effort to establish its reviving nuclear industry as a competitive option against Russia's "all-exclusive package" nuclear energy deals and China's approach to foreign infrastructure development. A number of collaborating U.S. agencies have developed a playbook attempting to counter strategic state-backed financing: (1) the Development Finance Corporation, which can make foreign debt and equity investments on behalf of the U.S. government, (2) the Export-Import Bank of the United States, which provides financing and loan guarantees to exporting firms, and (3) the FIRST Program,³⁷¹ an initiative for staff at the Department of State, Department of Energy, and National Nuclear Security Administration (NNSA) to help lay technical groundwork in "nuclear newcomer" countries and imbue alignment with nonproliferation

367 Most of the nuclear reactors used to generate energy around the world are non-advanced reactors. But demand for advanced reactors, considered "Generation III+" and "Generation IV" designs, is growing due to improved safety and flexibility. Advanced reactors can come in a variety of sizes, ranging from microreactors (1 MW to 20 MW), SMRs (20 MW to 300 MW), and full-size reactors (300 MW to 1,000+MW). See Office of Nuclear Energy, "Advanced Reactor Technology Development Fact Sheet," U.S. Department of Energy (2019). <https://www.energy.gov/ne/articles/advanced-reactor-technology-development-fact-sheet>. Accessed December 19, 2024.

368 Joanne Liou, "What are Small Modular Reactors?" IAEA Office of Public Information (September 13, 2023). <https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs>. Accessed December 16, 2024.

369 Stephen Goldberg and Robert Rosner, "Nuclear Reactors: Generation to Generation," American Academy of Arts & Sciences (2011), pp. 7-17. <https://www.amacad.org/sites/default/files/academy/pdfs/nuclearReactors.pdf>. Accessed December 16, 2024.

370 U.S. Department of Energy, "DOE Announces \$900 Million to Accelerate the Deployment of Next-Generation Light-Water Small Modular Reactors," (June 17, 2024). <https://www.energy.gov/articles/doe-announces-900-million-accelerate-deployment-next-generation-light-water-small-modular>. Accessed December 16, 2024.

371 FIRST stands for Foundational Infrastructure for Responsible use of SMR Technology.

standards.³⁷² With SMR feasibility studies and pre-investment determinations underway in at least 20 different countries around the world, the race for the global market remains in its early stages.³⁷³

Secondly, the U.S. government has also enacted tariff rate increases to counter unfair and non-market practices by China (e.g., forced technology transfers, intellectual property theft, and exorbitant government subsidies). The 2024 tariff rates include an increase from 25% to 100% on EVs imported from China, 7.5% to 25% on lithium-ion EV batteries, and 25% to 50% on solar cells.³⁷⁴ According to the Biden administration's announcement on the tariff increases:

China's forced technology transfers and intellectual property theft have contributed to its control of 70, 80, and even 90% of global production for the critical inputs necessary for our technologies, infrastructure, energy, and health care—creating unacceptable risks to America's supply chains and economic security. Furthermore, these same non-market policies and practices contribute to China's growing overcapacity and export surges that threaten to significantly harm American workers, businesses, and communities.³⁷⁵

Additional countries have enacted import tariffs on Chinese-made energy technologies. In 2024, the European Union (EU) imposed provisional tariffs on imports of Chinese-made EVs upwards of 37.6% after conducting an anti-subsidy investigation, and Canada also increased its tariff rate on Chinese-made EVs to 100%.³⁷⁶

The features defining the U.S. competitive approach to energy technologies include:

- Led by U.S. private sector, which conducts basic research into energy technologies and leads the development, demonstration, and deployment of technologies
- U.S. government and Department of Energy's national laboratories conduct basic research to advance energy innovation and technological discoveries

372 U.S. International Development Finance Corporation, "Report on DFC's Financing Nuclear Energy-Related Projects Overseas" (March 2024), <https://www.dfc.gov/sites/default/files/media/documents/DFC%20Report%20-%20Civilian%20Nuclear%20Energy%202024.pdf> (accessed December 16, 2024); Export-Import Bank of the United States, "U.S. EXIM Small Modular Reactor Financing Toolkit," (November 23, 2023), <https://www.exim.gov/policies/small-modular-reactor-financing> (accessed December 16, 2024); U.S. Department of State, "Program to Create Pathways to Safe and Secure Nuclear Energy Included in Biden-Harris Administration's Bold Plans to Address the Climate Crisis," (April 27, 2021), <https://www.state.gov/program-to-create-pathways-to-safe-and-secure-nuclear-energy-included-in-biden-harris-administrations-bold-plans-to-address-the-climate-crisis/> (accessed December 16, 2024).

373 Alec Mitchell, "Small Modular Reactor Global Tracker," World Nuclear Association (November 14, 2024). <https://world-nuclear.org/information-library/current-and-future-generation/small-modular-reactor-smr-global-tracker>. Accessed December 16, 2024.

374 The White House, "FACT SHEET: President Biden Takes Action to Protect American Workers and Businesses from China's Unfair Trade Practices" (May 14, 2024). <https://www.whitehouse.gov/briefing-room/statements-releases/2024/05/14/fact-sheet-president-biden-takes-action-to-protect-american-workers-and-businesses-from-chinas-unfair-trade-practices/>. Accessed December 16, 2024.

375 Ibid.

376 Weihuan Zhou and Henry Gao, "Major Economies are Taking Aim at China's EV Industry. Here's What to Know," World Economic Forum (September 16, 2024). <https://www.weforum.org/stories/2024/09/major-economies-are-taking-aim-at-china-s-ev-industry-here-s-what-to-know/>. Accessed December 19, 2024.

- U.S. government is taking an increasingly active stance to support basic research and technology development by U.S. companies to counter Russia and China’s state-led approaches³⁷⁷
- U.S. government subsidies (mainly in the form of tax incentives to renewable energy producers) have been used to stimulate domestic deployment³⁷⁸ but deployment is mainly market driven by prices
- U.S. government (along with some Western counterparts) have begun enacting tariffs to address Chinese unfair trade and non-market practices and “dumping”³⁷⁹ of cheap energy technologies, such as solar panels and electric vehicles

Strategic Advantage: What are the United States, China, and Russia competing for?

Strategic advantage is broadly defined as the benefits (or advantages) gained by a country that establishes a competitive edge or favorable position over its competitors. It is “strategic” because the advantages go beyond the initial technology and economic benefits to more “strategic” spheres of influence such as geopolitical leverage, stronger diplomatic ties, and economic, investment, and import dependencies. When a dominant energy exporter has these strategic advantages, it can attempt to influence policy decisions in countries dependent on them, either directly through coercion or pressure, or indirectly through the cultivation of commercial and political relationships.

The CGSR publication *Examining the Energy Transition Through the Lens of Great Power Competition*, published in August 2023, provides several examples of how China and Russia have used strategic advantages in relation to their energy industries to yield favorable outcomes on the global stage. Examples illustrate how strategic advantages can be used to shield countries from international condemnation even when they run afoul of international norms, deter heavy sanctions from being waged against them, and be used to threaten or impose trade and/or investment restrictions.

For example, after Russia’s invasion of Crimea in 2014, European countries dependent on Russia for energy did not support “stringent sanctions aimed at Russia’s energy sector.”³⁸⁰ After Russia’s invasion of Ukraine in February 2022, “Russia’s role as a dominant energy supplier globally limited the West’s ability to implement secondary sanctions,” and as a result sanctions have not had a notable

377 Through the 2021 Bipartisan Infrastructure Law and the 2022 Inflation Reduction Act, the U.S. government increased the availability of loans, loan guarantees, and grants to support private sector with demonstration and commercialization. However, the level of support going forward is uncertain. International Energy Agency, “United States 2024: Energy Policy Review” (2024), pp. 87-88. <https://iea.blob.core.windows.net/assets/b5826832-7182-4abe-9041-01c9f000d69d/UnitedStates2024.pdf>. Accessed December 19, 2024.

378 “During FY 2016–22, nearly half (46%) of federal energy subsidies were associated with renewable energy, and 35% were associated with energy end uses. Federal support for renewable energy of all types more than doubled, from \$7.4 billion in FY 2016 to \$15.6 billion in FY 2022.” U.S. Energy Information Administration, “Federal Financial Interventions and Subsidies in Energy in Fiscal Years 2016–2022” (August 1, 2023). <https://www.eia.gov/analysis/requests/subsidy/>. Accessed December 19, 2024.

379 The United States and others have accused China of “dumping” or flooding markets with its relatively lower-cost solar panels (supported by Chinese subsidies), making it difficult to establish a domestic solar industry. For more, see Christopher Casey, “Circumvention Inquiry into Solar Imports.”

380 See Fernando Garcés De Los Fayos and Krzysztof Bartzczak, *Energy as a Tool of Foreign Policy of Authoritarian States, in Particular Russia*, European Parliament (April 2018). [https://www.europarl.europa.eu/RegData/etudes/STUD/2018/603868/EXPO_STU\(2018\)603868_EN.pdf](https://www.europarl.europa.eu/RegData/etudes/STUD/2018/603868/EXPO_STU(2018)603868_EN.pdf). Accessed December 13, 2024.

effect on the level of Russian oil exports and revenue.³⁸¹ Russia's invasion of Ukraine in 2022 offers an additional example:

After the invasion of Ukraine, Western countries left Russia's nuclear-related exports largely un-sanctioned because of the world's reliance on it, including the United States and Europe, as Russia is the world's top exporter of enriched uranium and exporter of nuclear reactors for power generation. Many non-Western countries dependent on Russian nuclear services and materials have remained at the very least neutral during its invasion, including India, China, South Africa, and Iran, though there are likely additional factors underlying their positions.³⁸²

Just as several countries were reluctant to openly condemn Russia for its invasion of Ukraine, in part probably because many of these countries count on Russian oil, gas, and nuclear-related exports—the same is likely to happen if China invades Taiwan in the future. Several countries depend on China for non-energy and energy technologies, equipment, investments, and finance.³⁸³ For instance, China allegedly used its foreign direct investment to persuade nine countries to reverse diplomatic recognition of Taiwan.³⁸⁴ Furthermore, over the past decade China has been increasingly relying on economic coercion, in the form of trade and investment restrictions, to influence policy decisions in other countries and “signal its displeasure of a country or entity that is undermining Beijing's interests.”³⁸⁵

Out of all energy technologies, perhaps the most strategic advantages can be gained from nuclear energy collaborations. Nuclear agreements allow providers to lock in “economic partnerships potentially lasting up to 100 years, encompassing all stages of its lifecycle, from design to decommissioning.”³⁸⁶ This can help providers, like the United States, China, or Russia, to cultivate long-term political and commercial relationships with purchasing countries.

Deep supplier dependencies can make the buyer-seller relationship across borders more akin to client and patron. Washington accuses Moscow of pushing its Build-Own-Operate model in this manner as a way of cultivating “strategic dependency,” as it has long criticized China of similarly doing

381 Asmeret Asghedom, “Examining the Energy Transition through the Lens of Great Power Competition,” p. 61.

382 *Ibid.*, p. 160.

383 *Ibid.*, pp. 27, 36.

384 S. Kalyanaraman, “War by Other Means: Geoeconomics and Statecraft by Robert D. Blackwill and Jennifer M. Harris,” *Strategic Analysis* 41, no. 6 (2017), pp 591-594. <https://doi.org/10.1080/09700161.2017.1377897>. Accessed December 13, 2024.

385 Asmeret Asghedom, “Examining the Energy Transition through the Lens of Great Power Competition,” p. 56; Fergus Hunter, Daria Impiombato, Yvonne Lau, and Adam Triggs, “Countering China's coercive diplomacy,” Australian Strategic Policy Institute, Policy Brief 68 (February 2023), <https://www.aspi.org.au/report/countering-chinas-coercive-diplomacy> (Accessed December 19, 2024).

386 Asmeret Asghedom, “Examining the Energy Transition through the Lens of Great Power Competition,” p. 76; U.S. Department of Energy, “Restoring America's Competitive Nuclear Energy Advantage” (2020), <https://www.energy.gov/articles/restoring-americas-competitive-nuclear-energy-advantage> (accessed December 19, 2024).

through its Belt and Road Initiative.³⁸⁷ This leverage could manifest in a variety of political influence tools, from synergy with diplomatic missions on the benign end to sabotage or total grid disruption on the other.³⁸⁸ For example, Rosatom has underwritten deals with “uncertain upfront financing and equally uncertain prospects for long-term commercial gain,” because sometimes “even bad deals can make for good geopolitics.”³⁸⁹

Growing interest globally in nuclear energy also presents economic and commercial opportunities. Since 2020, more than 30 countries have updated their national energy policies to include or expand both traditional and advanced nuclear fission power. The International Energy Agency now recommends a doubling of its share within the global energy mix by 2050 to achieve decarbonization goals, with dozens of countries making even further commitments to a tripling.³⁹⁰ Amid a surging growth outlook, the nuclear energy policy team at Third Way estimated a potential global market size of about \$387 billion annually by 2050.³⁹¹

Lastly, perhaps what the United States most stands to lose is leadership over the nuclear nonproliferation regime it has so painstakingly steered and enforced through the last several decades. A 1974 Department of State report on nonproliferation strategy asserted that “a vigorous program of commercial nuclear cooperation with other nations can help maintain influence over foreign programs through proper controls, dependence on external supply, and the confidence of a constructive association in peaceful programs”³⁹²—a conviction that appears resurgent today. If U.S. initiative in the nonproliferation policy process and enforcement were to recede, it remains unclear if any authority would step up to fill the gap, and if so, how their differing priorities could alter the governance landscape safeguarding the peaceful use of fission technology.³⁹³ Beijing has

387 Christopher Ford, “The Civil Nuclear Sector, Nonproliferation, and Great Power Competition: Rebuilding Global Leadership,” U.S. Department of State Bureau of International Security and Nonproliferation (September 16, 2020). <https://2017-2021.state.gov/the-civil-nuclear-secto-nonproliferation-and-great-power-competition-rebuilding-global-leadership/>. Accessed December 30, 2024.

388 Kacper Szulecki and Indra Overland, “Russian Nuclear Energy Diplomacy and its Implications for Energy Security in the Context of the War in Ukraine,” *Nature Energy* 8 (2023), pp. 413-421. <https://doi.org/10.1038/s41560-023-01228-5>. Accessed December 30, 2024.

389 Andrew Weiss and Eugene Rumer, “Nuclear Enrichment: Russia’s Ill-Fated Influence Campaign in South Africa,” Carnegie Endowment for International Peace (December 16, 2019). <https://carnegieendowment.org/research/2019/12/nuclear-enrichment-russias-ill-fated-influence-campaign-in-south-africa?lang=en>. Accessed December 30, 2024.

390 “Net Zero Roadmap: 2023 Update,” International Energy Agency (September 2023), pp. 150-152, <https://www.iea.org/reports/net-zero-roadmap-a-global-pathway-to-keep-the-15-0c-goal-in-reach> (accessed December 30, 2024); “Six More Countries Endorse the Declaration to Triple Nuclear Energy by 2050 at COP29,” World Nuclear Association (November 13, 2024), <https://world-nuclear.org/news-and-media/press-statements/six-more-countries-endorse-the-declaration-to-triple-nuclear-energy-by-2050-at-cop29> (accessed December 30, 2024).

391 This assumes 16% of new electricity demand is served by nuclear power by 2050, and a tariff of \$90/MWh. See Alan Ahn et al., “2024 Update: Map of the Global Market for Advanced Nuclear,” Third Way (October 24, 2024). https://thirdway-generated-pdfs.s3.us-east-1.amazonaws.com/products/111744/2024_Map_of_the_Global_Market_for_Advanced_Nuclear_Future_Demand_is_Bigger_Than_Ever.pdf. Accessed December 30, 2024.

392 Fred Ikle and Winston Lord, “Analytic Staff Meeting on Non-Proliferation Strategy,” Department of State (July 31, 1974). <https://nsarchive2.gwu.edu/nukevault/ebb467/docs/doc%206%207-31-74%20PPS-ACDA%20paper%20for%20staff%20meeting.pdf>. Accessed December 30, 2024.

393 Rebecca Davis Gibbons, *The Hegemon’s Toolkit* (Ithaca, NY: Cornell University Press, 2022), p. 169.

a concerningly lax history with proliferation, while Moscow's recent actions and rhetoric are highly deleterious to the efficacy of long-held nuclear norms.³⁹⁴

Given the importance of gaining strategic advantages in the nuclear energy industry, we will provide a case study illustrating current competition to develop a new nuclear technology—fusion energy.

Case Study: Fusion Energy

Fusion energy is rapidly shifting from an unprecedented international collaborative effort to an all-out competition, with two major powers—the United States and China—vying to win the race. To grasp the nature of the competition, it is essential to consider the impact of government policies and funding, the varying technological priorities of different countries, and the collaborations forming between private enterprises and public institutions. Therefore, by examining these factors, we can gain valuable insights into the strategies employed by the two major players and implications for technological innovation and energy policy. The United States and China have taken two drastically different approaches to develop their domestic fusion industries, but it remains unclear which will ultimately gain the strategic advantage of bringing sustainable fusion energy to the grid.

The United States achieved a major fusion breakthrough in 2022 when the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory (LLNL) achieved the first recorded fusion ignition, producing more energy than was input.³⁹⁵ This milestone has generated renewed global interest and investment in fusion energy, underscoring collaborative and competitive efforts to develop a sustainable and transformative energy source for the future. Despite this milestone, the road to fusion energy has several challenges that still need to be concurred, such as improved plasma confinement, fuel self-sufficiency, and identifying materials that can withstand the over 100 million degrees Celsius conditions. Despite these challenges, the fusion industry still remains optimistic that viable commercial fusion power will become available in the 2040s or 2050s.

What is Fusion Energy?

Fusion energy fundamentally differs from traditional nuclear power, which relies on fission. In fission, a heavy isotope (like uranium and plutonium) absorbs a neutron, becomes unstable, and splits into lighter isotopes, releasing energy as heat to generate electricity.³⁹⁶ In contrast, nuclear fusion combines light isotopes (typically hydrogen isotopes deuterium and tritium) to form heavier isotopes, releasing massive amounts of energy in the process. This same reaction powers the sun and stars, and scientists hope to replicate this reaction in a controlled environment through a fusion reactor

394 U.S. Naval Institute Staff, "Report to Congress on Chinese Nuclear Weapons," U.S. Naval Institute (October 9, 2024), <https://news.usni.org/2024/10/09/report-to-congress-on-chinese-nuclear-weapons> (accessed December 30, 2024); Heather Williams, "Why Russia Keeps Rattling the Nuclear Saber," Center for Strategic and International Studies (May 20, 2024), <https://www.csis.org/analysis/why-russia-keeps-rattling-nuclear-saber> (accessed December 30, 2024).

395 U.S. Department of Energy, "DOE National Laboratory Makes History by Achieving Fusion Ignition" (December 12, 2022). <https://www.energy.gov/articles/doe-national-laboratory-makes-history-achieving-fusion-ignition>. Accessed October 11, 2024.

396 EUROfusion, "Fusion vs Fission," <https://euro-fusion.org/fusion/fusion-vs-fission/>. Accessed October 9, 2024.

by generating and sustaining plasma (or a very hot gas) at extremely high temperatures of over 100 million degrees Celsius.³⁹⁷

Fusion addresses many concerns associated with fission. Fusion produces minimal long-term radioactive waste, presents a limited risk for proliferation as no enriched materials are used, and fusion reactor components are potentially recyclable in about 100 years, compared to millions of years for fission.³⁹⁸ Additionally, fusion eliminates the risk of nuclear meltdowns, as plasma cools rapidly in an accident, halting the reaction. Fusion reactions generate nearly four million times more energy than burning fossil fuels and four times more than nuclear fission, offering the potential for abundant and low-carbon energy if successfully harnessed.³⁹⁹

Table 1. Leading Fusion Energy Concepts

Fusion Designs	Description ⁴⁰⁰	Government R&D ⁴⁰¹	Private R&D ⁴⁰²
Tokamak	A tokamak is a sophisticated fusion energy device that uses strong magnetic fields to confine plasma in a donut-shaped chamber, enabling the fusion of hydrogen isotopes to generate clean and virtually limitless energy. Several experimental tokamaks are in operation worldwide.	<ul style="list-style-type: none"> • International Thermonuclear Experimental Reactor (ITER)* • DEMO (proposed successor to ITER) • JT-60SA* (Japan & EU) • JET* (EU) • KSTAR* (South Korea) • DIII-D* (U.S.) • EAST* (China) • CFETR* (China) • EU-DEMO* (Euratom) • DEMO-RF* (Russia) • JA-DEMO* (Japan) • K-DEMO* (South Korea) 	<ul style="list-style-type: none"> • Commonwealth Fusion Systems (U.S.) • Tokamak Energy (U.S.) • Energy Singularity Fusion Power Technology (China) • ENN (China) • Startorus Fusion (China)

397 Ibid.; “DOE Explains...Fusion Energy Science,” U.S. Department of Energy, <https://www.energy.gov/science/doe-explainsfusion-energy-science> (accessed January 2, 2024).

398 ITER, “Fusion Energy, Advantages of Fusion.” <https://www.iter.org/fusion-energy/advantages-fusion>. Accessed October 9, 2024.

399 Ibid.

400 Robert J. Goldston, “An Overview of the Fusion Landscape,” *Bulletin of the Atomic Scientists* (November 12, 2024). <https://thebulletin.org/premium/2024-11/an-overview-of-the-fusion-landscape/#post-heading>. Accessed November 14, 2024.

401 Fusion Industry Association, *The Global Fusion Industry 2024* (July 2024), <https://www.fusionindustryassociation.org/fia-launches-2024-global-fusion-industry-report/> (accessed October 12, 2024); IAEA, *IAEA World Fusion Outlook 2024* (2024), <https://www.iaea.org/publications/15777/iaea-world-fusion-outlook-2024> (accessed November 19, 2024).

402 Ibid.

Stellarator	A stellarator is a type of fusion energy device that uses complex, twisted magnetic fields to confine plasma in a helical shape, allowing for the potential of sustained nuclear fusion without the need for the large electric currents required in tokamaks.	<ul style="list-style-type: none"> • Wendelstein 7-X* (Germany) • MUSE* (U.S.) 	<ul style="list-style-type: none"> • Type One Energy (U.S.) • Thea Energy (U.S.) • Gauss Fusion (Germany) • Proxima Fusion (Germany)
Magnetic Mirror	A magnetic mirror fusion system is a plasma confinement device that utilizes magnetic fields to create a reflective barrier at both ends of a linear chamber, trapping charged particles to sustain the conditions necessary for nuclear fusion.		<ul style="list-style-type: none"> • Realta Fusion (U.S.) • Novatron (N4) Fuson (Sweden)
Field-Reversed Configuration	A Field-Reversed Configuration (FRC) fusion system is a compact magnetic confinement device that utilizes a self-reversed magnetic field to stabilize and confine plasma in a toroidal shape, aiming to achieve efficient nuclear fusion with lower construction costs and enhanced performance.		<ul style="list-style-type: none"> • Helion (U.S.) • Tae Technologies (U.S.) • Princeton Fusion Systems (U.S.)
Flow-Stabilized Z-Pinch	A flow-stabilized Z-pinch fusion energy system is a plasma confinement technique that employs a high-current electric discharge to create a magnetic field that compresses and stabilizes the plasma, facilitating the conditions necessary for efficient nuclear fusion.		<ul style="list-style-type: none"> • ZAP Energy (U.S.) • Magneto Inertial Fusion Technologies Inc (MIFTI) (U.S.)
Magnetized Linear Inertial Fusion	A magnetized linear inertial fusion energy system combines magnetic confinement with inertial compression to create a high-density plasma state, using magnetic fields to stabilize the plasma while rapidly compressing it with powerful drivers to achieve the conditions required for nuclear fusion.	<ul style="list-style-type: none"> • Z-Pulsed Power Facility at Sandia National Lab* (U.S.) 	<ul style="list-style-type: none"> • FUUSE (Canada)

Inertial Fusion Energy (IFE) Indirect Drive	Inertial fusion energy indirect drive uses high-energy lasers to generate X-rays in a hohlraum, which then compress a deuterium-tritium pellet to achieve the conditions necessary for nuclear fusion.	<ul style="list-style-type: none"> • National Ignition Facility (NIF) at Lawrence Livermore National Laboratory* (LLNL) (U.S.) • Laser Megajoule* (France) • SG-III* (China) • UFL-2M Tsar Laser* (Russia) 	<ul style="list-style-type: none"> • Longview Fusion Energy Systems (U.S.)
Inertial Fusion Energy (IFE) Direct Drive	Inertial fusion energy direct drive involves using high-energy lasers to directly illuminate and compress a fusion fuel pellet, achieving the conditions necessary for nuclear fusion without the intermediary step of generating X-rays.		<ul style="list-style-type: none"> • Focused Energy (U.S. & Germany) • Xcimer Energy (U.S.) • HB11 (Australia) • Marvel Fusion (Germany)
Inertial Fusion Energy (IFE) Fast Ignition	Fast ignition in inertial fusion energy differs from traditional systems by using a two-step process that first compresses the fuel pellet and then applies a separate, high-intensity energy pulse to ignite it, aiming for greater efficiency and reduced energy input.		<ul style="list-style-type: none"> • EX-Fusion (U.S., Japan, Australia)

*Experimental

Cooperation in the Development of Fusion Energy

Fusion energy research began in earnest in the 1950s and 1960s, following the discovery of fusion in the 1930s. Early efforts focused on developing plasma confinement methods, notably the tokamak in the Soviet Union and the stellarator in the United States, with the tokamak emerging as the more efficient design at the time.⁴⁰³ This led to international collaboration, exemplified by the establishment of the Joint European Torus (JET) tokamak in 1973. A significant turning point came in 1985 when leaders from the United States and the Soviet Union agreed to work together on fusion energy research for peaceful purposes. This historic proposal expanded to broader international cooperation, including the EU (Euratom), China, Japan, South Korea, and India, culminating into the establishment of the International Thermonuclear Experimental Reactor (ITER) agreement signed in 2006, with a goal of constructing a large-scale tokamak in France for fusion energy research.⁴⁰⁴

Construction of the ITER tokamak began in 2010 in France but has been plagued by constituent delays and cost overruns due to complications from international collaboration, design changes, natural disasters, and the Covid-19 pandemic, to name a few. This led to the announcement in 2024 that the experiment's start date would be postponed until 2039, with an estimated cost increase of

403 EUROfusion, "History of Fusion." <https://euro-fusion.org/fusion/history-of-fusion/>. Accessed October 10, 2024.

404 ITER, "Status of the Organization." <https://www.iter.org/about/legal-resources/status-organization>. Accessed October 10, 2024.

\$5 billion.⁴⁰⁵ At its inception, ITER was estimated to cost around \$5 billion total; however, the most recent cost estimates have it projected at costing well over \$20 billion.⁴⁰⁶ A former director-general of ITER identified concerns that contributed to delays, such as tensions between members like Russia and the United States starting in 2014 stemming from the annexation of Crimea, which likely have worsened following the invasion of Ukraine in 2022.⁴⁰⁷ Collaborations among Russia, China, the United States, India, Japan, South Korea, and the EU have struggled with ongoing delays from production holdups, cost overruns, and management issues; however, all members have remained committed and involved in the monumental effort.⁴⁰⁸

While ITER aims to be the definitive experiment for global fusion energy viability, private fusion companies are increasingly more likely to achieve sustained burning plasmas before it does. Nevertheless, ITER remains crucial for the international scientific community, as it will be able to test key aspects of fusion, such as tritium breeding at scale. The knowledge gained from ITER will be shared with all members and likely with the private industry as well. Although ITER will not be the first to achieve a net energy gain—an accomplishment reached by LLNL in 2022—its goal is still to be the first to demonstrate long-lived sustainable burning plasma, suitable for energy production.

From Cooperation to Competition

While fusion research began as a collaborative effort to tackle one of science's most significant challenges, culminating in the establishment of ITER, competition among major powers has persisted behind the scenes throughout this initiative. Nearly all ITER member countries have developed domestic fusion research facilities and reactors to advance their own capabilities while remaining committed to the goals of ITER. In particular, private industry in the United States has attracted substantial investments and government funding to explore various fusion energy concepts, all vying to be the first to deliver sustainable commercial fusion energy to the market. China has also achieved notable progress in its fusion research, dedicating substantial resources to initiatives such as the Experimental Advanced Superconducting Tokamak (EAST) and targeting a breakthrough in fusion technology by the 2040s. As a result, the United States and China have emerged as leaders in fusion energy research and development, with their competition in this field becoming an aspect of the broader strategic rivalry between these two great powers.

The United States and China have both made the development of fusion energy a national priority. In February 2025, under the Trump administration, a Department of Energy Secretarial Order included nuclear fusion in a list of emerging technologies that will be prioritized for research and

405 Elizabeth Gibney, "ITER Delay: What It Means for Nuclear Fusion," *Nature* 631 (2024), pp. 488-489. <https://doi.org/10.1038/d41586-024-02247-2>. Accessed October 12, 2024.

406 Charles Seife, "World's Largest Fusion Project Is in Big Trouble, New Documents Reveal," *Scientific American* (June 15, 2023). <https://www.scientificamerican.com/article/worlds-largest-fusion-project-is-in-big-trouble-new-documents-reveal/>. Accessed October 12, 2024.



407 Elizabeth Gibney, "Five-year delay would spell end of ITER," *Nature* (2014). <https://www.nature.com/articles/nature.2014.15621>. Accessed October 12, 2024.

408 Elizabeth Gibney, "ITER Delay: What It Means for Nuclear Fusion."

development (R&D) funding.⁴⁰⁹ In October 2025, the Trump administration released its Fusion Science & Technology Roadmap, which presented a comprehensive national strategy for the development and commercialization of fusion energy by the mid-2030s. In 2024, the Biden administration unveiled the Bold Decadal Vision for Commercial Fusion Energy to help support the financing, regulatory environment, and research into commercial fusion energy.⁴¹⁰ The U.S. Department of Energy then launched a milestone-based fusion development program, which allows public funding to be given to private fusion startups only upon achievements of targeted milestones in the fusion research, which reduces the risk for U.S. taxpayers.⁴¹¹

The U.S. approach to fusion development is heavily reliant on private investment. The Fusion Industry Association (FIA) estimates that there are around 45 private companies (26 in the United States) that have raised over \$7 billion in private funding.⁴¹² The U.S. government aims to reduce the regulatory burden on U.S. companies, clearing the pathway to bring fusion energy to the grid faster.

Table 2. Leading U.S. Private Fusion Companies

Commercial Fusion Company	Fusion Energy System Design	Investment (Public/Private)	Established ⁴¹³
 Commonwealth Fusion Systems	Tokamak	Private: \$1.8-2 Billion ⁴¹⁴ Public: \$15 Million ⁴¹⁵	2018
 Tokamak Energy	Tokamak	Private: \$200 Million ⁴¹⁶ Public: \$50 Million	2009

409 "Secretary Wright Acts to 'Unleash Golden Era of American Energy Dominance,'" U.S. Department of Energy (February 5, 2025). <https://www.energy.gov/articles/secretary-wright-acts-unleash-golden-era-american-energy-dominance>. Accessed February 13, 2025.

410 The White House, "Readout of the White House Summit on Developing a Bold Decadal Vision for Commercial Fusion Energy," (April 19, 2022). <https://www.whitehouse.gov/ostp/news-updates/2022/04/19/readout-of-the-white-house-summit-on-developing-a-bold-decadal-vision-for-commercial-fusion-energy/>. Accessed November 14, 2024.

411 "Realta Fusion Partners with U.S. Department of Energy for Groundbreaking Milestone Based Fusion Development Program," University of Wisconsin-Madison (June 7, 2024). <https://innovate.wisc.edu/realta-fusion-partners-with-u-s-department-of-energy-for-groundbreaking-milestone-based-fusion-development-program/>. Accessed November 14, 2024.







412 Fusion Industry Association, "The Global Fusion Industry 2024."

413 Ibid.

414 "Commonwealth Fusion Systems Raises \$1.8 Billion in Funding to Commercialize Fusion Energy," Commonwealth Fusion Systems (November 11, 2021). <https://cfs.energy/news-and-media/commonwealth-fusion-systems-closes-1-8-billion-series-b-round>. Accessed October 12, 2024.

415 "Commonwealth Fusion Systems Signs \$15 Million DOE Agreement To Advance Commercial Fusion Energy," Commonwealth Fusion Systems (June 6, 2024). <https://cfs.energy/news-and-media/cfs-signs-15-million-doe-agreement-to-advance-commercial-fusion-energy>. Accessed October 12, 2024.

416 Kai Nicol-Schwarz, "Commercialising the energy that powers the sun: UK nuclear fusion startup Tokamak Energy raises \$50m," Sifted (January 7, 2024). <https://sifted.eu/articles/nuclear-fusion-startup-tokamak-energy-raises-50m>. Accessed October 12, 2024.

	Stellarator	Private: \$20 Million ⁴¹⁷ Public: Unknown	2022
	Stellarator	Private: \$82.4 Million ⁴¹⁸ Public: Unknown	2019
	Magnetic Mirror	Private: \$12 Million ⁴¹⁹ Public: \$3 Million ⁴²⁰	2022
	Field-Reversed Configuration	Private: \$1.2 Billion ⁴²¹ Public: \$17.4 Million ^{*422}	1998
	Field-Reversed Configuration	Private: \$600 Million ^{**423} Public: \$9 Million	2013
	Inertial Fusion Energy (IFE) Direct Drive	Private: \$100 Million ⁴²⁴ Public: \$9 Million ⁴²⁵	2022

417 Tim De Chant, “Thea Energy raises \$20M Series A for pixel-inspired fusion power plants,” TechCrunch (February 8, 2024). <https://techcrunch.com/2024/02/08/thea-energy-series-a/>. Accessed October 12, 2024.

418 “Type One Energy Group Finalizes \$82.4M Seed Financing Round,” Type One Energy (July 30, 2024). <https://typeoneenergy.com/type-one-energy-group-finalizes-82-5m-seed-financing-round/>. Accessed October 12, 2024.

419 “After breaking a fusion world record, Realta Fusion is at “an inflection point,” University of Wisconsin-Madison (July 26, 2024). <https://innovate.wisc.edu/after-breaking-a-fusion-world-record-realta-fusion-is-at-an-inflection-point/>. Accessed October 12, 2024.

420 Mehdi Anvarian, “Madison startup gains federal backing to continue nuclear fusion research,” Realta Fusion (January 1, 2024). <https://realtafusion.com/news/madison-startup-gains-federal-backing-to-continue-nuclear-fusion-research/>. Accessed October 12, 2024.




421 Tracxn, “TAE Technologies Funding & Investors.” https://tracxn.com/d/companies/tae-technologies/_rBhBqa3BmG4RbocqiL1AjryMJRgcUrOvZhk4KSi0kZU/funding-and-investors#summary. Accessed October 12, 2024.

422 “Clean Fusion Energy Leader TAE Technologies Wins \$17.4M CalCompetes Grant,” TAE Technologies (November 2022). <https://tae.com/clean-fusion-energy-leader-tae-technologies-wins-17-4m-calcompetes-grant/>. Accessed October 12, 2024.

423 Lisa Stiffler, “OpenAI Reportedly in Talks with Helion Energy to ‘Buy Vast Quantities’ of Fusion Power,” GeekWire (June 3, 2024). <https://www.geekwire.com/2024/openai-reportedly-in-talks-with-helion-energy-to-buy-vast-quantities-of-fusion-power/>. Accessed October 12, 2024.

424 “Xcimer Raises \$100 Million to Put Inertial Fusion Energy on Path to Commercialization,” Xcimer Energy Corporation (June 4, 2024). <https://xcimer.energy/xcimer-raises-100-million-to-put-inertial-fusion-energy-on-path-to-commercialization/>. Accessed October 12, 2024.

425 “Xcimer Energy Announces \$9 Million US Department of Energy Award to Develop Laser-Driven Inertial Fusion Energy,” Xcimer Energy Corporation (May 31, 2023). <https://xcimer.energy/xcimer-energy-announces-9-million-us-department-of-energy-award-to-develop-laser-driven-inertial-fusion-energy/>. Accessed October 12, 2024.

 FOCUSED ENERGY	Inertial Fusion Energy (IFE) Fast Ignition	Private: \$82 Million ⁴²⁶ Public: \$3 Million	2021
 ZAP ENERGY	Flow-Stabilized Z-Pinch	Private: \$330 Million ⁴²⁷ Public: \$5 Million ⁴²⁸	2017
 PACIFIC FUSION	Pulsed Magnetic Fusion System (IFE)	Private: \$900 Million ⁴²⁹ Public: Unknown	2023

*** Grant from the State of California.

**A promise of \$1.8 Billion of additional funding is getting unlocked if deadlines are met.⁴³⁰

While the U.S. approach remains heavily reliant on private industry, China’s approach is heavily focused on government funded and directed projects. The current Chinese Five-Year plan (2021-2025) made comprehensive research facilities for fusion projects a national priority, which has been supported with nearly \$1.5 billion annually in government funding towards fusion.⁴³¹ While the United States has been the leader in fusion research since the 1950s, China has gone from a non-player two decades ago to a potential future leader in fusion research with world-class facilities in part due its sustained government investment and a strong desire to be the first country to bring fusion energy to the grid.

The approaches of the United States and China towards fusion are distinct, and this is reflected in the varying fusion energy design concepts they choose to support. The United States has taken the approach of investing in a wide variety of fusion energy system designs. The 10 leading private fusion companies in the United States, many of which have received government funding, employ a range of approaches, including tokamaks, stellarators, magnetic mirrors, field-reversed configurations, inertial fusion energy (IFE) direct drive, IFE fast ignition, and flow-stabilized z-pinch designs. China on the other hand has two main fusion enterprises—the Institute of Plasma Physics at Hefei Institute of

426 “Focused Energy Raises \$82 Million in Funding to Advance Laser-Based Nuclear Fusion,” PR Newswire (June 22, 2023). <https://www.prnewswire.com/news-releases/focused-energy-raises-82-million-in-funding-to-advance-laser-based-nuclear-fusion-301857630.html>. Accessed October 12, 2024.

427 Tracxn, “Zap Energy Company Profile.” https://tracxn.com/d/companies/zap-energy/_OVvI2vo5Oh_Gvhc_-yKbhmd2Rygg-VbbWo70z7-LlI0#about-the-company. Accessed October 12, 2024.

428 Lisa Stiffler, “Zap Energy lands \$5M federal grant and ‘vote of confidence’ in pursuit of fusion power,” GeekWire (May 31, 2023). <https://www.geekwire.com/2023/zap-energy-lands-5m-federal-grant-and-vote-of-confidence-in-pursuit-of-fusion-power/>. Accessed October 12, 2024.

429 Lizze Mushangwe, “Pacific Fusion Comes out of Stealth Mode with \$900m Funding Announcement,” Fusion Energy Insights (November 14, 2024). <https://fusionenergyinsights.com/blog/post/pacific-fusion-comes-out-of-stealth-mode-with-900m-funding-announcement>. Accessed May 22, 2025.




430 Lisa Stiffler, “OpenAI Reportedly in Talks with Helion Energy to ‘Buy Vast Quantities’ of Fusion Power.”

431 Gemma Conroy, “Inside China’s Race to Lead the World in Nuclear Fusion,” *Nature* 632 (2024), pp. 968-970. <https://doi.org/10.1038/d41586-024-02759-x>. Accessed November 15, 2024.

Physical Science and the privately funded ENN Group.⁴³² The Chinese government-funded research is almost exclusively focused on developing tokamaks, beginning with the Experimental Advanced Superconducting Tokamak and eventually the China Fusion Engineering Test Reactor (CFETR) experimental tokamaks.⁴³³

Although the U.S. private fusion industry is far ahead of the Chinese private industry, following the recent upsurge in private fusion investment in the United States, similar interest is starting to grow in China with a few fusion startups starting to attract investment and media spotlight.⁴³⁴ A Chinese fusion energy startup, Energy Singularity, built its first tokamak prototype in just three years, faster than what has been built in the United States.⁴³⁵ This demonstrates that China not only has the technical capabilities, but also financial support to catch the United States and potentially surpass the United States in fusion energy research and development.

Table 3. Leading Chinese Private Fusion Companies

Commercial Fusion Company	Fusion Energy System Design	Investment (Total USD) ⁴³⁶	Established ⁴³⁷
 能量奇点 ENERGY SINGULARITY	Tokamak	\$110 Million	2021
 ENN 新奥	Tokamak	\$386 Million	2019
 STARTORUS FUSION 星环聚能	Tokamak	\$69 Million	2021
Neo Fusion (50/50 Government partnership with Nio Inc)	Unknown	\$690 Million	2023

432 Fusion Industry Association, “Chinese Fusion Energy Programs Are A Growing Competitor in the Global Race to Fusion Power.” <https://www.fusionindustryassociation.org/chinese-fusion-energy-programs-are-a-growing-competitor-in-the-global-race-to-fusion-power/>. Accessed November 15, 2024.

433 Ibid.

434 Qianni Chen, “Twilight in the Nuclear Fusion Industry: Rise of Private Companies,” Integral. <https://www.integralnewenergy.com/?p=38642>. Accessed November 15, 2024.

435 Angela Dewan and Ella Nilsen, “The U.S. led on nuclear fusion for decades. Now China is in position to win the race,” CNN (September 19, 2024). <https://www.cnn.com/2024/09/19/climate/nuclear-fusion-clean-energy-china-us/index.html>. Accessed November 15, 2024.

436 Qianni Chen, “Twilight in the Nuclear Fusion Industry: Rise of Private Companies.”

437 Fusion Industry Association, “The Global Fusion Industry 2024.”

In early 2024, the Chinese government proceeded to establish a new national industrial consortium dedicated to the development and advancement of nuclear fusion technology, which further supports its stance that fusion energy will strengthen China's comprehensive national power if achieved. This consortium, led by the China National Nuclear Corporation (CNNC), aims to pool national resources to accelerate the progress of fusion technology in China.⁴³⁸ As China develops its private fusion industry, it maintains a consistent government stance that the tokamak design is the most promising, in contrast to the U.S. approach, which is exploring a wider range of options.⁴³⁹ It remains to be seen whether the government-led approach taken by China or the private sector-led approach of the United States will bring viable fusion energy to the market first.

However, the incredible advancements that China has been able to make in a very short period cannot be discredited. Its EAST experimental tokamak is the world's first fully superconducting tokamak, which has led China to already begin construction on CFETR that might demonstrate fusion energy production of 200-1000 MW, potentially years ahead of ITER.⁴⁴⁰ China's EAST tokamak and its private industry tokamak built by Energy Singularity already outpaces any tokamaks currently in operation in the United States. The United States does not currently have anything like it. The Princeton Plasma Physics Laboratory has been trying to upgrade its tokamak for a decade, and the only other operating tokamak in the United States is the DIII-D tokamak, which is over 30 years old, highlighting that there are no modern fusion facilities currently in the United States.⁴⁴¹ If the United States desires to continue to lead in fusion energy research and development it must continue to increase its support for the leading private industry domestically, as the lack of modern national fusion facilities demonstrates the effects of inconsistent government support for the industry over the years.⁴⁴²

A Look Beyond the United States and China

The United States and China might be the world leaders in fusion research and development, but they are not alone. The EU, United Kingdom, Japan, and South Korea are all heavily investing in fusion research. In 2014, all EU member states that had established fusion research centers signed an agreement to create the European Consortium for the Development of Fusion Energy, referred to as EUROfusion. The EUROfusion budget from 2021 to 2025 was estimated to consist of around \$549 million from the European Atomic Energy Community (Euratom) and approximately \$450 million in matching funds from member states.⁴⁴³ The United Kingdom joined the EUROfusion consortium adding significant fusion research facilities and making them available to all the consortiums members. The UK operates the Joint European Torus (JET) at the Culham Center for Fusion Energy; JET began operating in 1983 and was the world's largest and most advanced experimental tokamak of its

438 "China Launches Fusion Consortium to Build Artificial Sun," American Nuclear Society (January 9, 2024). <https://www.ans.org/news/article-5668/china-launches-fusion-consortium-to-build-artificial-sun/>. Accessed November 15, 2024.

439 Qianni Chen, "Twilight in the Nuclear Fusion Industry: Rise of Private Companies."

440 Jinxing Zheng et al., "Recent progress in Chinese fusion research based on superconducting tokamak configuration," *The Innovation* 3, no. 4 (2022). <https://doi.org/10.1016/j.xinn.2022.100269>. Accessed November 15, 2024.

441 Angela Dewan and Ella Nilsen, "The US Led on Nuclear Fusion for Decades. Now China is in Position to Win the Race."

442 Ibid.

443 EUROfusion, "About EUROfusion" <https://euro-fusion.org/eurofusion/>. Accessed November 15, 2024.

time. JET was the first experimental tokamak to successfully achieve deuterium-tritium experiments achieving world record fusion power for its time starting in 1997.⁴⁴⁴

Similar to the United States, the UK has also seen an increase in private fusion startups, and it is collaborating with certain U.S.-based fusion companies. TAE Technologies and Tokamak Energy, both U.S.-based fusion companies that have received U.S. government funding, also have research locations in the UK. The UK has multiple domestic private companies that have started to receive substantial investment in recent years. First Light Fusion, an inertial confinement fusion company, has received nearly \$100 million in funding, and Pulsar Fusion, which is developing a propulsion system that uses nuclear fusion, has received over \$110 million in funding.⁴⁴⁵

In April 2023, Japan announced a national strategy for fusion energy, aiming to foster greater collaboration between industry, academia, and the government to bring fusion energy to fruition in Japan. The strategy not only aims to further support Japan's research interests in international collaborations, such as ITER, but also seeks to commercialize fusion technology and build a fusion industry ecosystem.⁴⁴⁶ Japan has multiple private fusion companies receiving considerable government funding including Kyoto Fusionering (\$90 Million), Helical Fusion (\$20 million), and EX-Fusion (\$12 million).⁴⁴⁷

In July 2024, the South Korean government announced \$863 million investment over 10 years with the aim of making South Korea a leader in developing fusion energy.⁴⁴⁸ This investment followed fusion scientists in South Korea achieving a world record for sustaining a fusion plasma with a temperature exceeding 100 million degrees Celsius for 48 seconds at the Korean Institute of Fusion Energy's KSTAR experimental tokamak in April 2024.⁴⁴⁹

444 Culham Centre for Fusion Energy, "JET is the World's Largest and Most Advanced Tokamak." <https://ccfe.ukaea.uk/programmes/joint-european-torus/>. Accessed November 16, 2024.

445 Fusion Industry Association, "The Global Fusion Industry 2024."

446 Kyoto Fusionering, "Japan's Fusion Energy Innovation Strategy," Fusion Energy Insights (May 17, 2023). <https://fusionenergyinsights.com/blog/post/japan-s-fusion-energy-innovation-strategy>. Accessed November 16, 2024.

447 Fusion Industry Association, "The Global Fusion Industry 2024."

448 "South Korea's bold \$863.7 Million Fusion Investment to Ensure Energy Leadership," Fusion Energy Insights (August 20, 2024). <https://fusionenergyinsights.com/blog/post/south-korea-s-bold-863-7-million-fusion-investment-to-ensure-energy-leadership>. Accessed November 16, 2024.

449 Laura Paddison, "'Artificial Sun' Sets Record for Time at 100 Million Degrees in Latest Advance for Nuclear Fusion," CNN (April 1, 2024). <https://www.cnn.com/2024/04/01/climate/nuclear-fusion-record-korea-climate-intl/index.html>. Accessed November 16, 2024.

Table 4. Major Players in Nuclear Fusion

Major Players	Government Funding 2023 (Total \$)	Private Funding 2023 (Total \$)	Technical Accomplishments	Future Goals
United States	~\$1.4 Billion (Annually between Fusion (\$763 Million) and ICF Research (630 Million)).	~\$5 Billion	- As of June 2025, achieved fusion ignition eight times since 2022 at LLNL National Ignition Facility, with the last achieving 8.6 megajoules (MJ) in April 2025. ⁴⁵⁰	- Leverage public/private partnerships to close the fusion R&D gaps. - Fusion pilot plants in the 2030s and commercial deployment in 2040s.
China	~\$1-1.5 Billion (Annually)	~\$1.2 Billion	- EAST achieved sustained plasma at 120 million °C for 101 seconds and 160 million °C for 20 seconds. ⁴⁵¹	- China Fusion Engineering Test Reactor (CFETR), a DEMO test reactor with aims to achieve fusion power above 1000 MW. - Aims for commercial fusion energy at scale by 2050.
United Kingdom	~\$814 Million (Through 2027)	Unknown	-UK's JET first to achieve fusion power using D-T fuel. - First plasma 1983 - Experiments with tritium 1991 - JET achieves world fusion power record at 16.1 MW in 1997.	- STEP (Spherical Tokamak for Energy Production) demonstration of net energy and fuel self-sufficiency by early 2040s.

450 Lawrence Livermore National Laboratory, "NIF Sets Power and Energy Records." <https://lasers.llnl.gov/about/keys-to-success/nif-sets-power-energy-records>. Accessed June 30, 2025.

451 Fusion Industry Association, "Chinese Fusion Energy Programs Are A Growing Competitor in the Global Race to Fusion Power."

South Korea	~\$863 Million (Over 10 years)	Unknown	- KSTAR sustained plasma with a temperature of 100 million °C for 48 seconds in 2024. ⁴⁵²	- KSTAR aims to be able to achieve sustained plasma at 100 million °C for 300 seconds by 2026. - K-DEMO aims to demonstrate fusion electrical power by 2050.
Japan	~+122 Million (Not comprehensive; only includes major contributions)	Unknown	- JT-60SA, the world's largest superconducting experiment, tokamak achieved its first plasma in 2023. - JT-60SA was built in partnership with the EU.	- JA-DEMO achieve over 1500 MW demonstration by 2040s-2050s.

*Note: While Russia remains engaged in the ITER project, little is known about the extent of Russia's spending on fusion energy research and development.

The nation that successfully brings viable fusion energy to the market will not only gain a competitive edge but also significant strategic advantage in shaping the international regulations that will follow. This dynamic is reminiscent of the United States role in establishing the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) and the International Atomic Energy Agency (IAEA).

In sum, the landscape of fusion research has shifted from global cooperation, as demonstrated with the ITER experiment, to intense competition primarily between the two great powers, the United States and China. While the United States emphasizes a robust private sector approach, leveraging significant investments and an increasingly supportive regulatory environment to explore diverse fusion technologies, China has rapidly advanced through substantial government funding and a focused commitment to tokamak development. Despite U.S. leadership in private fusion initiatives, it faces challenges with aging infrastructure and a lack of modern national facilities, while China has established world-class research capabilities and an increasingly emerging private fusion sector. As both nations strive for dominance in fusion energy, the outcome of this competition has the potential to not only shape the future of energy but also broader geopolitical dynamics, necessitating the U.S. government to enhance support for its fusion industry to achieve this strategic advantage.

452 Laura Paddison, "Artificial Sun' Sets Record for Time at 100 Million Degrees in Latest Advance for Nuclear Fusion."

Conclusion: Lessons Learned

The United States' competitive edge in scientific research and innovation will help it to keep pace in energy technology competition, especially as that competition intensifies to meet growing demand for low-carbon technologies that are reliable and affordable. Nuclear energy, fission, and fusion is an area of growing competition as it can provide reliable, baseload energy—as opposed to solar and wind energy which are intermittent sources. The United States has a rich history of innovating nuclear energy technologies that are safe and reliable, and it has an opportunity to leverage its expertise and scientific base to put forth better designs than its competitors. Moreover, the United States' leadership in additive manufacturing (also called 3D printing) can help it gain an edge on competitors if it succeeds at 3D printing of nuclear technologies and reducing manufacturing costs.⁴⁵³

However, the U.S. government must not only focus on achieving technological breakthroughs in new energy sources, like SMRs and fusion, but also on transforming technological achievements into international exports to reap the economic, political, and diplomatic benefits, hence gaining and keeping a strategic advantage over its adversaries. As a review of the past shows, the United States can innovate and bring new technologies to the market, but it has a history of losing its competitive edge and global market share to its adversaries.

As the United States continues to engage in energy competition, there are lessons learned from the past that should be applied to the future. In order to compete with China and Russia, the U.S. government needs to:

- Continue to take a proactive role in helping U.S. private sector companies through financial incentives and increase the involvement of U.S. national laboratories to aid in scientific research and development
- Foster deeper collaborations with allied countries to exploit comparative advantages and offset costs, particularly in the nuclear industry where U.S. allies like South Korea, Japan, and multiple European countries are also exporters of nuclear reactors and/or related parts and equipment⁴⁵⁴
- Increase the U.S. manufacturing and industrial base to manufacture energy technologies domestically (while leveraging innovations in advanced manufacturing and other emerging technologies) and incentivize and provide workforce training programs to plug existing workforce gaps such as in the mining industry⁴⁵⁵

453 Danny Weller, “Will Additive Manufacturing Power the Evolution of Nuclear Energy?” *Autonomous Manufacturing* (January 2024). <https://amfg.ai/2024/01/18/will-additive-manufacturing-power-the-evolution-of-nuclear-energy/#:~:text=3D%20Printing%20Optimizes%20Nuclear%20Supply%20Chain&text=Leveraging%20additive%20manufacturing%2C%20they've,through%20this%20cutting%20Dedge%20technology>. Accessed December 19, 2024.

454 For example, Gattie and Massey propose a U.S.-led global alliance and “a U.S. Civilian Nuclear Technology and Industrial Base that leverages allied nuclear expertise within a global network of services and technologies” that is “capable of competing with China and Russia in the deployment of nuclear technology, fuel, and services.” See David Gattie and Joshua Massey, “Twenty-First-Century US Nuclear Power: A National Security Imperative” *Strategic Studies Quarterly* 14, no. 3 (2020), pp 121-142. https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-14_Issue-3/Gattie.pdf. Accessed January 29, 2024.

455 Christina Lu, “Uncle Sam Wants You to Join the Mining Industry,” *Foreign Policy* (May 9, 2024). <https://foreignpolicy.com/2024/05/09/united-states-critical-minerals-mining-workforce-china/>. Accessed January 29, 2024.

- Ramp up efforts to “prevent China’s appropriation of U.S. innovation,”⁴⁵⁶ reduce opportunities for technology transfers to Chinese companies, and apply export controls on homegrown energy technologies and materials as new achievements are made by the United States
- Consider establishing or increasing local content requirements for foreign firms manufacturing energy technologies in the United States, such as the Chinese companies that are rapidly opening solar panel manufacturing facilities in the United States⁴⁵⁷

A major lesson learned from reviewing the evolution of energy technologies, especially nuclear and renewable energy, is that a “first mover advantage” is not guaranteed in the long run. A first mover advantage is defined as “a firm’s ability to be better off than its competitors as a result of being first to market in a new product category.”⁴⁵⁸ While that might initially be true, the first mover advantage does not always hold over time for all energy technologies, especially those with long supply chains, extensive manufacturing requirements, and high capital costs. While U.S. companies and U.S. national laboratories work on developing new or advancing old energy technologies, the U.S. policy community needs to formulate a contingency plan for ensuring future inventions and innovations are protected and result in long-term economic and political benefits for the United States.

456 Paul Dabbar, “U.S. Energy Superpower Status and a New US Energy Diplomacy.”

457 Chinese solar companies have been increasing solar manufacturing facilities in the United States, but they are importing the critical inputs to assemble the solar modules from China. According to a 2024 Reuters article, “Chinese companies will have at least 20 gigawatts’ worth of annual solar panel production capacity on U.S. soil within the next year, enough to serve about half of the U.S. market.” Nicola Groom, “Many U.S. Solar Factories are Lagging. Except Those China Owns,” Reuters (July 17, 2024). <https://www.reuters.com/business/energy/many-us-solar-factories-are-lagging-except-those-china-owns-2024-07-17/>. Accessed June 30, 2025.

458 Fernando F. Suarez and Gianvito Lanzolla, “The Half-Truth of First-Mover Advantage,” *Harvard Business Review* (April 2005). <https://hbr.org/2005/04/the-half-truth-of-first-mover-advantage#:~:text=A%20first%2Dmover%20advantage%20can,and%20longevity%20of%20early%20success>. Accessed December 19, 2024.

Competition in Cooperative Relationships: The Case of Russia and China's Naval Technology Cooperation

Kimberly Peh

Introduction

In 2022, Russia and China announced that “there are no ‘forbidden’ areas of cooperation” in their relationship.⁴⁵⁹ Within two years, 24 joint military exercises (nearly 25% of all such exercises since they began in 2003) were conducted,⁴⁶⁰ accompanied by an expansion in geographical scope and complexity. In international fora like the United Nations, Moscow and Beijing echo one another’s messages, amplifying rhetoric that supports the creation of a different international order. Since the war in Ukraine, trade between them surged and crossed \$200 billion as Russia turned to China for a greater variety of goods while China increased its energy imports from Russia.⁴⁶¹

With the enhanced cooperation, analysts have labeled Russia and China (sometimes alongside Iran and North Korea) as an “axis”⁴⁶² and raised concerns about the impact which their cooperation can have on the United States and allies’ interests and security. More consequentially, the U.S. and allies’ strategic advantage (that is, the state of being in a better position to achieve goals that matter to the great power competition) can be eroded because cooperation among adversaries can strengthen their individual military power and promote coordinated action that strains resources and complicates the United States and allies’ decision-making.

Yet, limits constrain Russia and China’s partnership. Since the 2022 joint statement, both Moscow and Beijing have refrained from talking about or acting on the institutionalization of an alliance. Moreover, despite their joint desire to counter the United States, they have independent and sometimes conflicting foreign policy goals and preferences. For instance, following Russia’s war on Ukraine, China’s economy has suffered because of the resultant global economic instability and trade cuts with key partners in Europe and South Korea. Meanwhile, Russia remains an important exporter of military equipment to India and Vietnam, both of which have ongoing disputes with China. Whereas Russia used to be the stronger country, the asymmetry now favors China, and this change,

459 Tony Munroe, Andrew Osborn, and Humeyra Pamuk, “China, Russia Partner up against West at Olympics Summit,” Reuters (February 4, 2022). <https://www.reuters.com/world/europe/russia-china-tell-nato-stop-expansion-moscow-backs-beijing-taiwan-2022-02-04/>. Accessed January 22, 2025.

460 Brian Hart, Bonny Lin, Matthew P. Funaiolo, Samantha Lu, Hannah Price, Nicholas Kaufman, and Gavril Torrijos, “How Deep Are China-Russia Military Ties?” *ChinaPower* (August 7, 2024). <https://chinapower.csis.org/china-russia-military-cooperation-arms-sales-exercises/>. Accessed January 22, 2025.

461 Anya Konstantinovskiy, “China-Russia Relations: January 2025,” Council on Foreign Relations (January 28, 2025). [https://www.cfr.org/article/china-russia-relations-january-2025#:~:text=Trade%3A%20China%2DRussia%20imports%20and,growth%20between%202022%20and%202023](https://www.cfr.org/article/china-russia-relations-january-2025#:~:text=Trade%3A%20China%2DRussia%20imports%20and,growth%20between%202022%20and%202023.). Accessed February 13, 2025.

462 Andrea Kendall-Taylor and Richard Fontaine, “The Axis of Upheaval: How America’s Adversaries Are Uniting to Overturn the Global Order,” *Foreign Affairs* (April 23, 2024), <https://www.foreignaffairs.com/china/axis-upheaval-russia-iran-north-korea-taylor-fontaine> (accessed February 12, 2025); Angela Stent, “Russia and China: Axis of Revisionists,” *Global China* (February 2020), <https://www.brookings.edu/articles/russia-and-china-axis-of-revisionists/> (accessed January 22, 2025).

along with the lack of congruent goals beyond their shared aim to undermine the United States, compound problems that bear upon the extent of their cooperation.

How can we understand and characterize the duality of cooperation and constraints in Russia and China's relationship? In this chapter, I argue that both can co-exist; in fact, Russia and China's partnership is bound not only by limits, but also competition. Competition goes beyond limits around cooperation. It introduces additional challenges because, besides the withholding of support, competition can also lead both sides to hurt one another. For policymakers, recognizing the co-existence of competition and cooperation is important for at least two reasons. If competition holds adversaries back from high-level coordination like joint military operations, the range of possible outcomes opened by cooperation can shrink, allowing policymakers to pay better attention to a smaller and more probable set of futures. If competition causes adversaries to hinder each other's progress, their internal friction can buy the United States and allies some time to get their own house in order and be better prepared to meet challenges posed by adversaries in the future. Thus, to characterize Russia and China's partnership, one needs to examine the full competitive-cooperative dynamic, where the competitive end goes beyond constraints on the partnership toward both sides hampering each other.

Recognizing that competition can exist within cooperation does not diminish the significance of the increase in level of cooperation between Russia and China and the pressure it poses to the United States and allies. Quoting the Commission on the National Defense Strategy, "China and Russia's 'no-limits' partnership ... has only deepened and broadened to include a military and economic partnership with Iran and North Korea, each of which presents its own significant threat to U.S. interests. This new alignment of nations opposed to U.S. interests creates a real risk, if not likelihood, that conflict anywhere could become a multi-theater or global war."⁴⁶³ Rather, this recognition adds to existing analyses by tracking, too, the changing level of competition, so that the net effect of their enhanced cooperation can be better estimated.

To study the competitive-cooperative dynamic in Russia and China's partnership, I examine their technology cooperation in the naval domain. Sino-Russian naval technology cooperation waxed and waned over the past 70 years. This long history allows it to exemplify the dynamic and the changing levels of competition and cooperation over time. Moreover, unlike longstanding frictions due to their shared territorial border (spanning more than 4,200 kilometers), the naval domain presents strong incentives for both Russia and China to cooperate because it draws attention away from potential territorial disagreements and helps strengthen China's ability to confront the United States when conflicts are primarily expected to occur at sea.⁴⁶⁴ Yet, even here, the case analysis shows that competitive dynamics underpin their collaboration from the start, with the Soviet Union trying to keep China's military power in check by providing it only with second-rate equipment and low-level know-how. Over time, their cooperation enhanced, brought about by improvements in the quality of

463 Jane Harman, Eric Edelman, John M. Keane, Thomas G. Mahnken, Mariah Sixkiller, Alissa Starzak, and Roger Zakheim, *Commission on the National Defense Strategy*, RAND (July 2024). https://www.armed-services.senate.gov/imo/media/doc/nds_commission_final_report.pdf, p. vi. Accessed January 22, 2025.

464 Jo Inge Bekkevold, "Imperialist Master, Comrade in Arms, Foe, Partner, and Now Ally? China's Changing Views of Russia," in *Russia-China Relations Emerging Alliance or Eternal Rivals?* Sarah Kirchberger, Svenja Sinjen, Nils Wörmer, eds. (Cham, Switzerland: Springer, 2022), pp. 49-50.

knowledge transfer and the move toward more joint development projects. Still, Russia's preference for keeping advanced technologies to itself and China's goal of self-sufficiency remained and continued to fuel disagreements. Such divergent interests keep competition salient and moderate the overall effect of their growing cooperation.

I develop this argument and analysis in the rest of this chapter. The next section elaborates the key concepts, competition and technology cooperation, and provides more justification for looking at Russia and China's naval technology cooperation. Then, the following section outlines the cooperative–competitive dynamic across three periods of their naval technology cooperation: 1950s–1960, 1990s–2000s, and from 2012 to now. Finally, the conclusion discusses policy implications for the United States and allies. It notes that, much like how competition persists in Russia and China's cooperative relationship in the naval domain, competition can similarly affect the U.S.'s own alliances. To prevent it from eroding the U.S. and allies' strategic advantage, states can benefit greatly from sorting out these differences now, before divergent goals and policy preferences start pulling allies apart in times of adversity.

Competition and Technology Cooperation in the Naval Domain

Key Definitions

Technology cooperation is a rarely defined term. Like technology, it is a concept of which everyone shares some baseline and has referents to guide conversations but does not have a concrete definition to delimit the term's boundaries. As such, while some studies regard both arms sales and joint exercises as indicators of the concept and others look at them separately, still others include only advanced technologies and innovation, narrowing their analyses to the transfers of emerging technologies, the co-establishment of high-tech parks, jointly applied patents, and mutual citations.

For a working definition that will be useful for the naval domain, I turn to the military's terminology for a start. In the military context, scholars and practitioners use the term military-technical cooperation (MTC). As Alexander Korolev describes it,

At the early stages, military-technical exchanges can be more of a structure for the parties to purchase military equipment or technological expertise from each other. As MTC moves into more advanced stages, however, it becomes more intertwined and is increasingly characterized by long-term projects for the joint design and production of arms and their components.⁴⁶⁵

According to this conceptualization, technology cooperation in the military consists in the exchange of military equipment and expertise between states. However, technology cooperation is not a dichotomy. It is conceived of as a continuum, such that there exist stages of cooperation. This feature is commonly alluded to but seldom specified by scholars and practitioners. Hence, to clarify the continuum, I build on Korolev's conceptualization and identify two attributes along which this continuum may vary.

465 Alexander Korolev, "On the Verge of an Alliance: Contemporary China-Russia Military Cooperation," *Asian Security* 15, no. 3 (2019), p. 236. Accessed February 13, 2025.

One way this continuum can vary is by the level of collaborative effort between states in the partnership. At the lowest level is a one-sided process. In military aid and arms sales, for example, military equipment and expertise can be transferred solely from one party to the other. As such, a minimal level of contribution is needed on the receiver's side to ensure the successful production and delivery of such goods and services. At the highest level is co-production. States are jointly responsible for the successful delivery of military equipment. Hence, at this end, they must pool resources and coordinate actions to achieve the desired outcome.

The second way the continuum can vary is by the sophistication of military equipment or expertise that is transferred or shared between the parties. Technical materials and knowledge can lie at the lowest level and moves along the continuum would represent the exchange of increasingly sensitive, complex, or hard to acquire capabilities, such as nuclear weapons and quantum technologies.

Put together, technology cooperation (in the military context) is the collaborative effort between states to deliver or exchange military equipment and expertise, and such effort can vary depending on the degree of contribution by states, *or* the quality of equipment and expertise. This two-dimensional conceptualization is not meant to fall neatly within a 2x2; hence, the "or" formulation, because extreme levels on one dimension can indicate a greater extent of technology cooperation. One can imagine, for instance, knowledge transfer in an area like quantum computing being classified as a higher level of cooperation than joint research and development (R&D) efforts between states on equipment like guns and tanks. Thus, details of the effort are crucial.

The second key concept is competition. With the renewed great power competition, the term "technology competition" has taken on a specific definition. However, I refer to competition here not as "technology competition," but the condition wherein states find themselves working toward a zero-sum outcome. A search for the meaning of competition brings up definitions like gaining superiority, trying to win, and trying to be better or more successful than another. These ideas imply that competition is about the fight to attain a goal or advantage, but this conceptualization is inaccurate. Instead, what defines competition is the zero-sum nature of the outcome because it is due to this nature that states are forced to pit themselves against one another, thereby making the process competitive even if it is not intended by states to make it so.

Following this definition, competition can happen—even if unintentionally—insofar as states have conflicting goals because one's success would lead to failure of the other. A classic example in international politics is the security dilemma. It might not be the case that a state, when working toward the objective, intends to reduce its neighbors' security. However, neighbors can still feel a diminished sense of security due to the threat that may be posed by the state.⁴⁶⁶

Competition and cooperation are not mutually exclusive. Between border countries, for example, competition can persist because there is always the potential for conflict. However, the competitive dynamic can either be allowed to define the relationship, track collaborative efforts, or stay at the background of their interactions. Figure 1 below shows a simplistic visualization of these respective scenarios, assuming linearity and general upward trends, with competition₁ exceeding cooperation, competition₂ paralleling cooperation, and competition₃ remaining at a low level across time. Hence,

466 See Shiping Tang, "The Security Dilemma: A Conceptual Analysis," *Security Studies* 18, no. 3 (2009), pp. 587-623. Accessed January 22, 2025.

relationships between states must be assessed based on the competitive–cooperative dynamic to properly characterize the relationship.

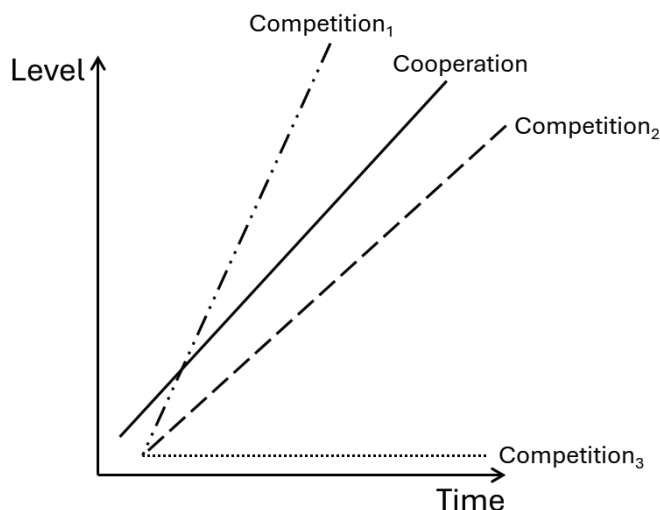


Figure 1: Stylistic Visualization of Cooperation and Competition Trends between Countries

Case Justification: Sino-Russian Naval Technology Cooperation

In the partnership between Russia and China, technology cooperation gained a preeminent spot because both see technological superiority as a crucial means to challenge the United States and achieve their goals. In a speech at the Nationwide Science and Technology (S&T) Awards Conference, President Xi Jinping remarked that “We must persist in innovation-led development ... and use S&T innovation to lead high-quality development and guarantee high-level security.”⁴⁶⁷ In February 2024, President Vladimir Putin approved Russia’s Scientific and Technological Development Strategy, which aims to use science and technology to address “strategic national priorities.”⁴⁶⁸

Specifically, technology cooperation in the naval domain serves as a good case study to demonstrate and examine the competitive–cooperative dynamic between Russia and China because it has a history of about 70 years. Naval arms sales date back to the early Cold War period, and beyond technology sharing, naval cooperation has gained heightened prominence in their partnership, starting with the routinization of joint naval exercises (“Joint Sea series,” 海上联合)⁴⁶⁹ since 2012. To

467 “Xi Jinping: Speech at the Nationwide S&T Conference, National Science and Technology Awards Conference, and the Conference of Academicians of CAS and CAE (June 24, 2024), CSET (July 3, 2024). <https://cset.georgetown.edu/publication/xi-jinping-cas-cae-conference-speech-2024/> (Translation by CSET). Accessed January 22, 2025. The original speech, “主要是：坚持党的全面领导，加强党中央对科技工作的集中统一领导... 以科技创新引领高质量发展、保障高水平安全。” can be found in: “受权发布 | 习近平：在全国科技大会、国家科学技术奖励大会、两院院士大会上的讲话,” Xinhua Net (June 24, 2024), <https://perma.cc/CY6X-GCP2>. Accessed January 22, 2025.

468 “Russia’s Scientific and Technological Development Strategy approved,” President of Russia (February 28, 2024), <http://en.kremlin.ru/acts/news/73579>. Accessed January 22, 2025.

469 Alexandre Sheldon-Duplaix, “Russia-China Naval Partnership and Its Significance,” in *Russia-China Relations Emerging Alliance or Eternal Rivals?*, Sarah Kirchberger, Svenja Sinjen, and Nils Wörmer, eds. (Cham, Switzerland: Springer, 2022), pp. 101-120.

signal support for each other and intimidate neighboring states, they also conducted these exercises in sensitive regions, such as the Baltic Seas and around the Senkaku Islands.⁴⁷⁰ Recent exercises have also grown to include countries like South Africa and Iran, reflecting an expansion in their reach and China's desire to become a "great maritime power" (海洋强国).⁴⁷¹ Overall, because both Russia and China consider themselves maritime nations,⁴⁷² the mutual benefits of joint development incentivize collaboration, making their relationship in this area suitable for investigating the competitive elements that underlie this cooperation.

At the same time, cooperation in the naval domain is less contentious than in the land domain, where uneasiness abounds. Between 1959 and 1966, political tensions led to a series of incidents occurring on China and the Soviet Union's shared border. When relations severely deteriorated, the Soviet Union moved forces to the border: "Bases were built or expanded, troops sent into Mongolia, and nuclear-tipped rockets emplaced."⁴⁷³ In March 1969, violence broke out in Damansky/Zhenbao (珍宝岛) Island, "mark[ing] a dangerous peak in the 'Sino-Soviet split.'"⁴⁷⁴ Following the conflict, relations between them froze until after the Cold War, when the 1991 Sino-Soviet Border Agreement was signed to reach an agreement on the border dispute.

Yet, as recent as in August 2023, China released a map depicting the Bolshoy Ussuriysky Island/Heixiazhi (黑瞎子岛), which lies on the border, as part of its territory. In 2024, Moscow and Beijing sought to address the underlying tension by launching a roadmap to jointly develop the island, but skepticism of their cooperation persists. Elizabeth Wishnick remarks that the roadmap "is both an indication of greater trust in the relationship and greater distrust because they [the Russians] feel they have to reinforce the message that it's a jointly administered island and [at the same time] say they want to cooperate with China in an area they consider strategic."⁴⁷⁵ Across different areas of the Sino-Russian relationship, the competitive-cooperative dynamic evidently exists, but in comparison, the naval domain is appropriate for examining the embedded competition because cooperation remains dominant, at least at present.

470 Richard Weitz, "Assessing Chinese-Russian Military Exercises Past Progress and Future Trends," Center for Strategic and International Studies (July 9, 2021). <https://www.csis.org/analysis/assessing-chinese-russian-military-exercises-past-progress-and-future-trends>. Accessed January 22, 2025.

471 Frank Jüris, "Sino-Russian Scientific Cooperation in the Arctic: From Deep Sea to Deep Space," in *Russia-China Relations Emerging Alliance or Eternal Rivals?* Sarah Kirchberger, Svenja Sinjen, and Nils Wörmer, eds. (Cham, Switzerland: Springer, 2022), p. 194.

472 Sheldon-Duplaix, "Russia-China Naval Partnership and Its Significance," p. 115.

473 Thomas W. Robinson, "The Sino-Soviet Border Dispute: Background, Development, and the March 1969 Clashes," RAND (August 1970), p. vi. https://www.rand.org/content/dam/rand/pubs/research_memoranda/2019/RM6171.pdf. Accessed January 22, 2025.

474 Ivanov, "Together and Apart: The Conundrum of the China-Russia Partnership."

475 Ekaterina Venkina, "One Island, Two Countries: A Look at How Chinese-Russian Relations are Playing Out in the Far East," Eurasianet (June 14, 2024). <https://eurasianet.org/one-island-two-countries-a-look-at-how-chinese-russian-relations-are-playing-out-in-the-far-east>. Accessed January 22, 2025.

Sino-Russian Naval Technology Cooperation

1950s – 1960: A Partnership burdened by Mistrust and the Prioritization of Conflicting Interests

Sino-Russian technology cooperation began in the 1950s. After the end of World War II, China aimed to build “a powerful navy” and laid out a phased approach to do so beginning with the attainment of manufacturing rights from the Soviet Union; then, the development of a semi-indigenous capability; and finally, the achievement of a fully indigenous production capability.⁴⁷⁶ To initiate the process, negotiations began in 1953 and an agreement was signed in June in which the Soviet Union agreed to provide China with 32 ships, 49 “semi-finished ships,” and “the right to transfer warships and produce mines without compensation.”⁴⁷⁷ In addition, the Soviet Union agreed to provide technical documents that would aid China in the manufacturing of ships, mines, and artillery.⁴⁷⁸

In the mid-1950s, the Soviet Union also worked with China to construct more advanced warships and submarines (e.g., the Riga-class destroyer escort, the W-class submarines, and the Kronstadt-class subchasers) in various shipyards across Shanghai.⁴⁷⁹ Later, in February 1959, both sides signed a second agreement that granted China the right to “receiv[e] designs and parts for the license production of submarines, two kinds of guided missile ships, and a hydro-foil torpedo boat.”⁴⁸⁰ By the end of the 1950s and early 1960s, China’s shipbuilding industry benefited so much from the Soviet Union’s assistance that it managed to build its own Chengdu-class frigate, the Romeo class (Type 031) submarine, and the Whiskey class submarines.⁴⁸¹

Yet, notwithstanding their brotherly relationship and the Soviet Union’s extensive support for China,⁴⁸² competing goals and an underlying security competition led to the ending of their partnership in 1960.

With the enormous aid it was pouring into China and their shared anti-imperialism ideologies, the Soviet Union thought that both countries were dedicated to the goal of countering the United States and its allies. Thus, when the Soviet Union needed a long-wave radio station to communicate with the submarines at sea, Nikita Khrushchev, then leader of the Soviet Union, decided that the joint construction of long-wave radio stations on China’s Hainan Island was the most feasible option, especially when the Soviet Union heavily funded the growth of China’s navy and China had itself

476 Srikanth Kondapalli, “China’s Naval Equipment Acquisition,” *Strategic Analysis* XXIII, no. 9 (1999). https://ciaotest.cc.columbia.edu/olj/sa/sa_99kos01.html. Accessed January 22, 2025.

477 “People’s Liberation Navy – History,” GlobalSecurity.org (2019). <https://www.globalsecurity.org/military/world/china/plan-history.htm>. Accessed January 22, 2025.

478 Ibid.

479 Captain E. J. Cummings, Jr., “The Chinese Communist Navy,” *U.S. Naval Institute* 90, no. 9/739 (September 1964), <https://www.usni.org/magazines/proceedings/1964/september/chinese-communist-navy>. Accessed January 22, 2025.

480 “People’s Liberation Navy – History,” GlobalSecurity.org.

481 Ibid.; Kondapalli, “China’s Naval Equipment Acquisition.”

482 Ivanov, “Together and Apart: The Conundrum of the China-Russia Partnership.”

requested assistance to meet such a need.⁴⁸³ However, prioritizing China's independence, Mao Zedong, then leader of the Chinese Communist Party, insisted that the construction project be fully funded and owned by China, adding that "the station could offer intelligence to the USSR [Union of Soviet Socialist Republics] during peacetime, and the USSR could send representatives to the station during times of war. However, under no circumstances would the USSR be allowed to establish military facilities on Chinese territory."⁴⁸⁴

As this disagreement went on, China requested assistance in the building of submarines, surface ships, and high-speed vessels to further develop its navy. In response, the Soviet Union counterproposed the development of a combined fleet, thinking that it would help in achieving their joint objective.⁴⁸⁵ However, the two proposals provoked Mao, who wanted only financial and technical aid from the Soviet Union—not a "joint cooperation."⁴⁸⁶ Moreover, Mao thought the proposals reflected the Soviet Union's belittlement of China and encroached on China's sovereignty; thus, he retorted:

You are no different than Stalin. You think that Chinese are savages covered with hair who are unable to accomplish modernization themselves and can only listen to you. ... First we must resolve the principal question: are we in charge and you are helping us or perhaps it is only a joint venture and if we do not agree to joint management then you will not help us, that is, you will shamelessly force us to accept it?⁴⁸⁷

To ensure that the Soviet leadership comprehended his "displeasure and contempt,"⁴⁸⁸ Mao also humiliated Khrushchev and his delegation during private talks in Beijing. Between egoistic personalities and conflicting priorities, the relationship between the two countries soured, which contributed to Khrushchev's decision to stop supporting China's nuclear weapons program and his refusal to aid China in developing nuclear submarines.⁴⁸⁹

The same problem of divergent and competing priorities played out in their foreign policy goals. When Khrushchev rose to power, the Soviet Union's goal was to maintain the status quo, as he sought

483 Alexander V. Pantsov and Nikita Yurievich Pivovarov, "The Secret Negotiations of N.S. Khrushchev and Mao Zedong, July-August 1958," Wilson Center (January 23, 2024), <https://www.wilsoncenter.org/publication/secret-negotiations-ns-khrushchev-and-mao-zedong-july-august-1958> (accessed January 22, 2025); Shen Zhiua, "Khrushchev, Mao and the Unrealized Sino-Soviet Military Cooperation," Parallel History Project on Cooperative Security (October 28, 2016), https://phpisn.ethz.ch/lory1.ethz.ch/collections/coll_china_wapa/Zhiua_englf409.html?navinfo=16034 (accessed January 22, 2025).

484 Zhihua Shen, ed., "Differences Over Domestic and Foreign Policies, 1957-1959," in *A Short History of Sino-Soviet Relations, 1917-1991* (Singapore: Palgrave Macmillan, 2016), p. 216.

485 Pantsov and Pivovarov, "The Secret Negotiations of N.S. Khrushchev and Mao Zedong, July-August 1958."

486 Shen, "Differences Over Domestic and Foreign Policies, 1957-1959," p. 217.

487 Pantsov and Pivovarov, "The Secret Negotiations of N.S. Khrushchev and Mao Zedong, July-August 1958."

488 Ibid.

489 Ibid.

to achieve a “peaceful coexistence” between the two great powers.⁴⁹⁰ However, China endeavored to address the Taiwan issue, which disrupted the status quo. In August 1958, China attacked Jinmen (an offshore island in the Taiwan Strait), and because the attack was launched shortly after Khrushchev’s visit to China, the United States thought it was planned by both Beijing and Moscow. In response, the U.S. declared its willingness to defend Taiwan, escalating the risk of a nuclear war between the United States and the Soviet Union. This incident and the entrapment risk frustrated the Soviet Union, which was all the more annoyed because Beijing neither informed nor consulted with Moscow before or even after the attack. Such differences in military and foreign policy preferences again surfaced when the Soviet Union stayed neutral in the Sino-Indian border conflict, which added to the growing number of problems that drove the termination of their cooperation in 1960.⁴⁹¹

Adding to the competitive dynamic, while China viewed its relationship with the Soviet Union through an instrumental lens and strove to use the collaboration to achieve its own goals over that of the partnership, the Soviet Union took advantage of the asymmetric relationship to hold back China—a “potential geopolitical rival” in the region.⁴⁹² As James Bussert and Bruce Elleman state,

Even during periods of so-called Sino-Soviet friendship, the USSR withheld modern and even standard FC [fire control] equipment on Chinese exports, *with the goal of keeping the Chinese navy weaker than their Soviet counterparts*, which increased after the 1960s split. For example, the Soviets removed Strut Curve and Drum Tilt fire control radars from the Osa-class missile attack craft sent to the PRC [People’s Republic of China] in the early 1960s and also withheld the 1952-vintage Owl Screech and Hawk Screech gun fire control radars.⁴⁹³

In evidence of their pragmatic relationship, China turned to the West when technological assistance by the Soviet Union was cut off. The United States took the opportunity to cooperate with China to divert the Soviet Union’s resources toward its shared eastern border with China. To formalize the technology transfers between the West and China, the Reagan administration approved arms trade with China within the Foreign Military Sales system, and China benefited tremendously from the chance to purchase and, in some cases, jointly produce such advanced equipment and technologies as missiles, naval gas turbines, and combat systems. However, this brief cooperation between China and the West ended when an embargo was institutionalized following the Tiananmen massacre in 1989.⁴⁹⁴

490 Mori Kazuko, “A Brief Analysis of the Sino-Soviet Alliance: The Political Process of 1957-1959,” Parallel History Project on NATO and the Warsaw Pact (June 2005), p. 4. <https://phpisn.ethz.ch/lory1.ethz.ch/publications/areastudies/documents/sinosov/Mori.pdf>. Accessed January 22, 2025.

491 Shen, “Differences Over Domestic and Foreign Policies, 1957-1959,” pp. 219-223.

492 Sarah Kirchberger, “Russian-Chinese Military-Technological Cooperation and the Ukrainian Factor,” in *Russia-China Relations Emerging Alliance or Eternal Rivals?* Sarah Kirchberger, Svenja Sinjen, Nils Wörmer, eds. (Cham, Switzerland: Springer, 2022), p. 76.

493 Emphasis in italics added. James C. Bussert and Bruce A. Elleman, *People’s Liberation Army Navy Combat Systems Technology, 1949-2010* (Annapolis, MD: Naval Institute Press, 2011), p. 5.

494 Kirchberger, “Russian-Chinese Military-Technological Cooperation and the Ukrainian Factor,” pp. 77-78.

1990s – 2000s: A Period of Increased Cooperation and Expanding Competition

After the embargo, China again cooperated with Russia to obtain military technological support. In addition to having few alternatives, Beijing was motivated to do so because it was shocked by the “impotence” of Iraq’s military in the face of the United States’s advanced technological capabilities during the Gulf War. As described by Alexandre Sheldon-Duplaix, “In an existential emergency, Beijing revised its strategic doctrine, moving from the concept of ‘winning local wars under normal conditions’ to the concept of ‘winning local wars under high technology conditions.’”⁴⁹⁵ Throughout the 1990s and 2000s, critical events like the 1996 Taiwan missile crisis and Taiwan’s steps towards declaring independence also urged China to reinvent its weapons industry,⁴⁹⁶ as its equipment was the equivalent of 1950s and 1960s technology. For Russia, the resumption of cooperation with China brought benefits because the arms sales helped improve its poor economy, sustained its military industrial complex, and provided an opportunity for Russia to sell the dated systems.⁴⁹⁷ Thus, another round of interest-based collaboration started.

In 1992, China and Russia signed an agreement to institutionalize their military-technical cooperation. Through the resultant commission (the Russia-China Mixed Intergovernmental Commission on Military-Technical Cooperation, or MICMTC), notable agreements were made, with the Shenyang Aircraft Corporation gaining the license to “assemble 200 Russian supermaneuverable Su-27 jet fighters.”⁴⁹⁸ After the Taiwan Strait crisis in 1996, both countries reached a higher level of technology cooperation through an agreement facilitating China’s acquisition of 12 Kilo-class submarines and 4 Sovremenny-class destroyers, all of which were purchased as “complete weapons systems.”⁴⁹⁹ These capabilities strengthened China’s navy by giving it access to technologies like combat direction systems, long-range air defense capabilities, and the Mineral-ME fire control radar.

495 Sheldon-Duplaix, “Russia-China Naval Partnership and Its Significance,” p. 103.

496 Throughout the two terms of Chen Shui-bian’s presidency in the 2000s, Chen acted on his intention to establish Taiwan as an independent country. He first did so by holding a domestic referendum in 2004 that sought voters’ response to two questions, including whether Taiwan should “acquire more advanced anti-missile weapons” in reaction to China’s continued to point its missiles at Taiwan. However, the referendum failed to pass because less than 50% of the eligible voters participated. In 2006, Chen sought to reform the constitution, which China viewed as “a timetable for ‘Taiwan Independence.’” Later, in 2008, the Taiwanese government put forth two referenda at the United Nations (UN) General Assembly, proposing that Taiwan be included in the UN under its own name. Each of these and other related activities were condemned by Beijing, which was reportedly determined to “pay any price” to prevent Taiwan’s independence. See Han Cheung, “Taiwan in Time: The dawn of the referendum era,” *Taipei Times* (December 2, 2018), <https://www.taipeitimes.com/News/feat/archives/2018/12/02/2003705330> (accessed January 22, 2025); “‘New Constitutions’ Means Timetable for Taiwan Independence,” Embassy of the People’s Republic of China in the United States of America (April 14, 2004). http://us.china-embassy.gov.cn/eng/zt/twwt/200404/t20040414_4912611.htm (accessed January 22, 2025); Kerry Dumbaugh, *Taiwan in 2004: Elections, Referenda, and Other Democratic Challenges*, Congressional Research Service (January 10, 2005), <https://sgp.fas.org/crs/row/RS21770.pdf> (accessed January 22, 2025).

497 Sheldon-Duplaix, “Russia-China Naval Partnership and Its Significance;” Ethan Meick, *China-Russia Military-to-Military Relations: Moving Toward a Higher Level of Cooperation*, U.S.-China Economic and Security Review Commission (March 20, 2017), p. 12. <https://www.uscc.gov/sites/default/files/Research/China-Russia%20Mil-Mil%20Relations%20Moving%20Toward%20Higher%20Level%20of%20Cooperation.pdf>. Accessed January 22, 2025.

498 Korolev, “On the Verge of an Alliance: Contemporary China-Russia Military Cooperation,” p. 240.

499 Sarah Kirchberger, “Russian-Chinese Military-Technological Cooperation and the Ukrainian Factor,” p. 79.

In fact, their cooperation burgeoned so much that China became the top importer of Russia's arms, accounting for up to 60% of all Russia's arms exports per year from 1999 to 2006.⁵⁰⁰

However, multiple problems plagued this period of cooperation, such that after 2006, arms sales between China and Russia dropped significantly, and they paused exchanges and meetings through the MICMTC.

First, on top of concerns within Russia that it might be arming an adversary, economic competition developed when China copied, illegally, Russian technologies and weapons designs through reverse engineering and espionage. Importantly, as a result of its improved production capabilities and success from reverse engineering, China became Russia's competitor in the global defense market as they were exporting capabilities to the same countries across Africa, Latin America, and Central and Southeast Asia.⁵⁰¹ Thus, when Russia's economy improved and its position in both old and new arms exports markets was secured, Moscow saw less need to depend on China—removing the strategic rationale that motivated cooperation during this period.⁵⁰²

Just as Russia lowered its dependence on China, Beijing perceived less need to import as extensively from Russia, as it was becoming a more self-sufficient arms producer. Indeed, while it purchased naval capabilities from Russia, China was simultaneously developing its own capabilities, which included the Yuan-class submarine, Luyang I and II destroyers, the Song-class diesel- or air-powered attack submarines, and the Jiangkai II class guided-missile frigate. In addition, it added to its forces the anti-ship cruise and ballistic missiles and amphibious ships, the variety of which enabled China to perform a wider range of operations like humanitarian assistance and naval diplomacy.⁵⁰³ To be sure, these additions were not modern by any means: they were “basically 1980s-era weapons systems,” and most, if not all, capabilities were produced through reverse engineering and the imitation of Russia's technologies.⁵⁰⁴ However, adaptations in various places, such as the integration of the “indigenously produced, vertically launched HHQ-9 SAM system and the phased-array Sea Eagle radar ... suggests that China may have mastered a potent air- and missile-defense technology that eluded Soviet technicians.”⁵⁰⁵ The brewing of an economic competition thus begun as China's advancements and replication of Russian technologies made them competitors in the market.

Second, conflicting interests, again, circumscribed the extent of their partnership. Russia continued to seek an advantage over China in military production capability. Thus, it refused to provide such information (e.g., maintenance blueprints) that would help China overcome technical problems, especially when China was breaching intellectual property rights and using the information and technical

500 Siemon T. Wezeman, “China, Russia and the Shifting Landscape of Arms Sales,” *Stockholm International Peace Research Institute* (July 5, 2017). <https://www.sipri.org/commentary/topical-background/2017/china-russia-and-shifting-landscape-arms-sales>. Accessed January 22, 2025.

501 Ibid.; Meick, “China-Russia Military-to-Military Relations,” p. 5.

502 Ibid.; pp. 12-13.

503 Congressional Research Service, *China Naval Modernization: Implications for U.S. Navy Capabilities—Background and Issues for Congress* (August 16, 2024), pp. 1-76. <https://sgp.fas.org/crs/row/RL33153.pdf>. Accessed January 22, 2025.

504 Richard Bitzinger, “Modernising China's Military, 1997-2012,” *China Perspectives*, no. 4 (2011), pp. 7-15. <https://doi.org/10.4000/chinaperspectives.5701>. Accessed January 22, 2025.

505 Andrew S. Erickson, “Can China become a Maritime Power?” in *Asia Looks Seaward: Power and Maritime Strategy*, Toshi Yoshihara and James Holmes, eds. (Westport, CT and London: Praeger Security International, 2008), pp. 70-110.

exchanges to reverse engineer Russia's capabilities.⁵⁰⁶ However, to bypass Russia, China obtained such information from Ukraine, which inherited major shipyards and facilities after the fall of the Soviet Union. China's behavior conflicted with Russia's preference for retaining specialized knowledge, which would allow it to carry on with selling arms and providing technical solutions to China.⁵⁰⁷

Inasmuch as China's behavior frustrated Russia, Russia's hesitance to offer extensive and sophisticated support irritated China, too. Reportedly, Russia's Rubin design bureau aided China in its submarine development.⁵⁰⁸ The Type 093 Shang-class nuclear-powered submarines was expected to match Russia's submarine designs in the 1970s, specifically the VICTOR III nuclear-powered submarine, in terms of noise level.⁵⁰⁹ However, if such support were indeed provided, the Rubin design bureau must have provided limited assistance because the expected improvements in speed and noise level were not met.⁵¹⁰ In fact, the Shang-class submarines were noisier than the initial expectations and possessed only slight improvements when compared to the first generation of nuclear submarines produced by China.⁵¹¹

Therefore, compared with the 1950s, the level of naval technology cooperation between Russia and China increased in terms of volume and sophistication. However, as the cooperation resumed out of individual interests, it could not sustain in the light of an emerging competition in the global arms market and the endurance of conflicting interests.

2012 – Present: Advanced Cooperation and Growing Wariness amid Changing Tides

Sino-Russian technology cooperation reinvigorated in 2012 when both President Putin and President Xi rose to power. Xi was inclined to cooperate because he needed to gain the military's support for his leadership. Moreover, while China had demonstrated some expertise in developing air and missile defenses, its ship-building abilities continued to suffer technical limitations, and broader military cooperation with Russia allowed the People's Liberation Army Navy (PLAN) to learn from Russia's combat experience, which was lacking in China.⁵¹²

When Russia annexed Crimea in 2014, Moscow leaned even more into its relationship with China as its ties with Europe and the United States strained, and sanctions compounded its economic

506 Dmitry Gorenburg, Elizabeth Wishnick, Paul Schwartz, and Brian Waidelich, "How Advanced is Russian-Chinese Military Cooperation?" *War on the Rocks* (June 26, 2023), <https://warontherocks.com/2023/06/29000/> (accessed January 22, 2025); Sarah Kirchberger, "Russian-Chinese Military-Technological Cooperation and the Ukrainian Factor," p. 81.

507 Sarah Kirchberger, *Assessing China's Naval Power: Technological Innovation, Economic Constraints, and Strategic Implications* (Berlin, Heidelberg: Springer-Verlag, 2015), p. 154.

508 Sarah Kirchberger, *China's Submarine Industrial Base: State-Led Innovation with Chinese Characteristics*, China Maritime Report No. 31 (September 29, 2023), p. 15. <https://digital-commons.usnwc.edu/cgi/viewcontent.cgi?article=1030&context=cmsi-maritime-reports>. Accessed January 22, 2025.

509 Christopher P. Carlson and Howard Wang, *A Brief Technical History of PLAN Nuclear Submarines*, China Maritime Report no. 30 (August 17, 2023), p. 7. <https://digital-commons.usnwc.edu/cgi/viewcontent.cgi?article=1029&context=cmsi-maritime-reports>. Accessed January 22, 2025.

510 Despite speculations, there is no concrete evidence indicating that the Rubin design bureau did assist China in the design of the nuclear submarines. Based on publications in China and technical analyses, Carlson and Wang suggest that such assessment that Russian technology and design assistance was provided is "premature." *Ibid.*, p. 9.

511 *Ibid.*, p. 10.

512 Kirchberger, *Assessing China's Naval Power*.

challenges, making China's huge population size an attractive market. By 2015, both sides concluded two significant arms deals, comprising the sale of the Project 677 Lada-class submarines, Su-35 fighter planes, and the S-400 air defense system. These deals were made possible by Moscow's push to reach an agreement and its lifting of restrictions that had prevented Russia from transferring sensitive military technologies. More importantly, these capabilities formed some of Russia's best-in-class systems—indicating an increase in Russia's willingness to sell more advanced equipment and sensitive technologies to China.⁵¹³ In 2019, Russia also announced that it will be aiding China in the development of a missile defense warning system, and in 2020, both countries declared that they will be co-developing non-nuclear submarines, which Sarah Kirchberger explained:

If this joint project actually comes to fruition, it would represent a significant departure from the previous arms trading relationship in which Russia was the (sometimes reluctant) provider and China the (not always trustworthy) recipient of advanced weapons. Jointly developing a strategically important weapons system such as a conventionally powered submarine signifies a hitherto unthinkable level of trust, as submarine technology counts among the most heavily guarded military secrets in any country that operates such systems and is not necessarily shared even between close allies.⁵¹⁴

Given the sophistication of these technologies and the move toward joint development efforts, the level of technology cooperation between the two appeared to have leapfrogged to the extent where “old sensitivities” had become less relevant in limiting their collaboration.⁵¹⁵ Yet, old and new competitive dynamics had similarly dialed up, bringing both cooperation and competition to higher levels.

Despite the joint nature of these R&D projects, contributions to and benefits gained from these projects have remained imbalanced against the backdrop of China's increased bargaining power and military growth.⁵¹⁶ Just as the Soviet Union had used the asymmetry to keep China in check, China had used the increased bargaining leverage to gain advantages at the expense of Russia. For instance, in the case of the 2014 Power of Siberia gas pipeline project, China leveraged its improved bargaining position to lock in a cheap gas price—“a lower price than the Russians had wanted, [which] will mean a loss for Russia, at least for the first several years”⁵¹⁷—that had enabled it to keep energy prices low.

513 Paul N. Schwartz, “The Changing Nature and Implications of Russian Military Transfers to China,” Center for Strategic & International Studies (June 21, 2021), <https://www.csis.org/analysis/changing-nature-and-implications-russian-military-transfers-china> (accessed January 22, 2025); Kirchberger, “Russian-Chinese Military-Technological Cooperation and the Ukrainian Factor,” pp. 88-89.

514 Kirchberger, “Russian-Chinese Military-Technological Cooperation and the Ukrainian Factor,” pp. 90-91.

515 Dmitry Gorenburg, “An Emerging Strategic Partnership: Trends in Russia-China Military Cooperation,” Marshall Center (April 2020). <https://www.marshallcenter.org/en/publications/security-insights/emerging-strategic-partnership-trends-russia-china-military-cooperation-0>. Accessed January 22, 2025.

516 Schwartz, “The Changing Nature and Implications of Russian Military Transfers to China.”

517 Alec Luhn and Terry Macalister, “Russia Signs 30-Year Deal Worth \$400bn to Deliver Gas to China,” *The Guardian* (May 21, 2014). <https://www.theguardian.com/world/2014/may/21/russia-30-year-400bn-gas-deal-china>. Accessed January 22, 2025.

On the flip side, while Russia had sought to use the opportunity to diversify its energy market, it finds itself now “at the mercy of a monopsonist buyer.”⁵¹⁸ In the same way, the joint development projects had remained “fairly one-sided”:⁵¹⁹

The recent “joint” heavy-lift helicopter project is a good example, as Russia’s role has reportedly been relegated to technical support and the provision of a transmission and tail rotor, even though it is reportedly transferring its core Mi-26 design technologies to China. Chinese chief designer Wu Ximing recently admitted as much, stating that “Our goal . . . is to learn from Russia’s strong points [in transmission design] and close the gap.” So far, the same could be said of the early warning system, since Russia has been officially awarded just a single contract for software development, although it is reportedly providing technical assistance on space control issues and possibly other aspects of the system as well.⁵²⁰

As these examples suggest, China had been making the most out of these developments to achieve the goal of enhancing its domestic production capabilities and gain access to Russia’s advanced technologies while Russia made greater compromises and accepted “more risk by relaxing strictures on the transfer of advanced Russian military technologies.”⁵²¹ Additionally, in areas where Russia seeks to cooperate, such as artificial intelligence (AI), China may gain even more bargaining leverage due to the continuing brain drain in Russia, the termination of international scientific collaborations with Russian scientists, and the crackdown on free speech⁵²²—all of which have “jeopardized [Russia’s] future technological competitiveness.”⁵²³

This shift in advantage and power asymmetry, which now tilts in favor of China, has major repercussions for Russia on the economic and security fronts. Economically, while Russia puts its resources into fighting wars, China has been filling gaps in the global arms market. It has made significant headways in many of the same markets where Russia dominates, and in Central Asia, China is now second only to Russia.⁵²⁴ Moving forward, should Beijing use its leverage to pressure Moscow to share more advanced and sensitive technologies, such as, submarine technology and

518 Sergey Vakulenko, “What Russia’s First Gas Pipeline to China Reveals About a Planned Second One,” *Carnegie Politika* (April 18, 2023). <https://carnegieendowment.org/russia-eurasia/politika/2023/04/what-russias-first-gas-pipeline-to-china-reveals-about-a-planned-second-one?lang=en>. Accessed January 22, 2025.

519 Schwartz, “The Changing Nature and Implications of Russian Military Transfers to China.”

520 *Ibid.*

521 *Ibid.*

522 Olga Dobrovidova, “Burning Bridges,” *Science* (November 9, 2023). <https://www.science.org/content/article/scientists-russia-struggle-world-transformed-its-war-ukraine>. Accessed February 13, 2025.

523 Jack A. Jarmon, “Scientists in Russia: Repressed, Imprisoned, in Exile, and “Out of the Game,” *Australian Outlook* (October 8, 2024). <https://www.internationalaffairs.org.au/australianoutlook/scientists-in-russia-repressed-imprisoned-in-exile-and-out-of-the-game/>. Accessed February 13, 2025.

524 “China Regional Snapshot: Central Asia,” *Foreign Affairs Committee* (October 25, 2022). <https://foreignaffairs.house.gov/china-snapshot-project-central-asia-2/#:~:text=Turkmenistan%20and%20Uzbekistan%20are%20the,military%20drones%20from%20the%20PRC>. Accessed January 22, 2025.

aircraft engines,⁵²⁵ Russia could lose its edge over China and even be superseded given China's rapidly advancing industrial base and economic prowess.⁵²⁶ Even through their technology cooperation, Russia may not be profiting as much as it desires. China has been purchasing capabilities that fill existing gaps in its production capabilities, which it continues to imitate. Hence, "repeat sales are increasingly rare," and the largely unidirectional transfer of high technology can further close the gap in their technological capabilities while widening the difference in their economies.⁵²⁷

With China's more modernized military vis-à-vis a weakening Russia, the security threat that China poses can become more salient even as they espouse a partnership that is anchored on a joint desire to challenge the United States. Reflecting Moscow's concern, Russia has focused on exporting and sharing defensive capabilities with China that would aid in achieving the overall objective. Some examples include the ballistic missile defense system, which Russia has promised to help China develop, and the S-400 air defense system.⁵²⁸ Conversely, in the case of offensive systems, Russia has shared only those which "would hardly prove decisive in a future conflict," and it has rejected China's request for capabilities like rocket engines, hypersonic missiles, and ground combat systems.⁵²⁹

Compared to the 1950s, security competition can play a bigger role in influencing their cooperation since the reality of Russia arming a potential adversary can become more pertinent. Furthermore, much like how their divergent foreign policy preferences in the 1950s had led them to undertake actions that hurt each other's interests, the same dynamic can be amplified today. Russia has continued to arm and maintain good relations with India and Vietnam (i.e., states in disputes with China), and hence, could persist in holding back on sharing technologies which China can use to coerce these countries. China's enduring tendency to prioritize its self-interests over their joint objective can also lead to increased friction as Beijing seeks greater influence in areas like Central Asia and the Arctic and appears to have little reservations about using its asymmetric leverage to take advantage of Russia.⁵³⁰

All things considered, it is perhaps unsurprising that despite ongoing rhetoric about the warm relationship between Moscow and Beijing, both have been reluctant to establish an alliance relationship. In 2021, Putin hedged on the issue of forming an alliance with China, stating that "Unlike NATO [North Atlantic Treaty Organization] countries, we are not trying to form any closed military alliance, there is no military bloc between Russia and China. We have no such intention."⁵³¹ Furthermore, in spite of the increasingly routinized and sophisticated joint naval exercises, these exercises barely reveal systems or information which are new to either side, and "Moscow does not

525 Andrea Kendall-Taylor, "The Axis of Upheaval: How the Convergence of Russia, China, Iran, and North Korea Will Challenge the U.S. and Europe," International Centre for Defence and Security (May 29, 2024). <https://icds.ee/en/the-axis-of-upheaval-how-the-convergence-of-russia-china-iran-and-north-korea-will-challenge-the-us-and-europe/>. Accessed January 22, 2025.

526 Wezeman, "China, Russia and the Shifting Landscape of Arms Sales."

527 Schwartz, "The Changing Nature and Implications of Russian Military Transfers to China."

528 Gorenburg, Wishnick, Schwartz, and Waidelich, "How Advanced is Russian-Chinese Military Cooperation?"

529 Schwartz, "The Changing Nature and Implications of Russian Military Transfers to China."

530 See Jüris, "Sino-Russian Scientific Cooperation in the Arctic: From Deep Sea to Deep Space."

531 "Russia-China Partnership not Directed Against Any Other Country: Putin," BRICS (October 22, 2021). <https://infobrics.org/post/34403/news/news/bankbrics/>. Accessed January 22, 2025.

appear to be committing its nuclear-powered submarines to naval exercises with China, an area in which its lead over China must be preserved.”⁵³² Thus, competition has clearly kept pace with the growing levels of cooperation as the longstanding roots of competition continue to undermine the partnership just as new ones emerge to complicate their relationship.

Conclusion

Technology cooperation between Russia and China has had its ups and downs throughout the last seven decades. However, focusing only on the three periods of naval technology cooperation, this chapter makes clear that collaboration between them has witnessed an upward trend. Initially, the partnership was largely one sided, with China being almost fully reliant on Russia for technological support. In the post-Cold War period, political and economic factors brought both countries together again. The MICMTC was established, and agreements were signed to facilitate arms sales and licensed productions that propelled the quality of China’s naval force. Over the past decade, warm relations between President Putin and President Xi further enhanced their collaboration. With Russia’s expressed willingness to share sensitive technologies and jointly develop submarines with China, the level of technology cooperation is arguably at a new peak given their joint R&D effort in a traditionally sensitive and strategic area.

Yet, competition between them has kept pace with the growing levels of cooperation. In the 1950s, Russia limited China’s access to more advanced weaponry, ensuring that Russia remained superior to China. Both sides had also prioritized the achievement of their conflicting goals, resulting in actions that undercut the other’s interest. Between the 1990s and 2000s, both sides again pursued their self-interests, leading Russia to refrain from sharing more information and technologies, and China to reverse engineer Russian capabilities while seeking information from alternative sources like Ukraine. During this time, China also became a competitor to Russia in the global defense market, introducing economic competition between them. Now, compounding the history of conflicting priorities and interests, China’s increased bargaining and military power relative to Russia has heightened their competition in both the economic and security domains, as China has become a greater contender in the global defense market and has better capabilities to threaten Russia’s territory, interests, and partners.

In short, cooperation and competition have co-existed at each given time throughout the Sino-Russian naval technology cooperation, and both levels have risen across the different time periods. This simultaneous increase in cooperation and competition does not undermine the fact that the United States and allies are more likely to face greater pressure and challenges due to their enhanced cooperation. However, because both have escalated over time, the net effect of these pressures and challenges is likely to be moderated since potential benefits of such elevated cooperation can be undercut by the negative consequences due to internal frictions. To depict this change in levels and contrast the level with the gap between competition and cooperation, I roughly map the levels onto the graph below, following the time periods covered in the case study above.

532 Sheldon-Duplaix, “Russia-China Naval Partnership and Its Significance,” p. 113.

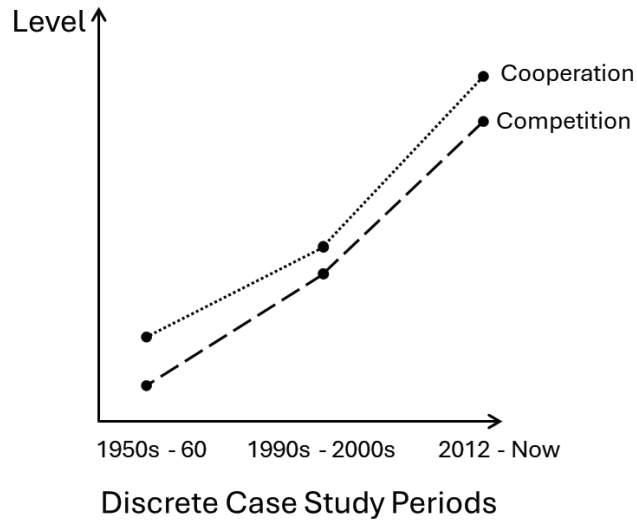


Figure 2: Stylistic Visualization of Cooperation and Competition Trends in Sino-Russian Naval Technology Cooperation Over Three Time Periods

Being aware of this competitive–cooperative dynamic is useful for two reasons. First, it allows U.S. policymakers to avoid overestimating the extent to which Russia and China might go to pursue a joint objective and,⁵³³ relatedly, the impact their cooperation can have on the United States and allies’ strategic advantage. Cooperation between states can open a wide array of possibilities, ranging from the sale and exchange of weapons and information to strategic coordination. However, depending on the balance between competition and cooperation, the probabilities assigned to each possible outcome can shift. Specifically, knowing that competition has not just constrained their collaboration, but also resulted in them hurting one another, can help with allotting lower probabilities to highly coordinated efforts while directing the United States and allies’ attention (for now) to the less coordinated but more probable scenarios that can follow from their cooperation.

Second, with the knowledge that competition can both limit and undermine partnerships, the United States and allies can use the time now to sort out any such differences that can hurt the alliance now or in the future. Existing analyses on the axis have suggested that the United States try to wedge apart Russia and China before their cooperation strengthened both their militaries and enhanced the depth of their strategic coordination. However, in addition to arguments noting the futility of such strategies,⁵³⁴ having a strategy that is primarily centered on slowing down the other side rather than advancing one’s own goal and advantages can be counterproductive. As athletes

533 See also Mark Cozad, Cortez A. Cooper III, Alexis A. Blanc, David Woodworth, Anthony Adler, Kotryna Juknevičiute, Mark Hvizda, and Sale Lilly, *Future Scenarios for Sino-Russian Military Cooperation: Possibilities, Limitations, and Consequences*, RAND (June 18, 2024). https://www.rand.org/pubs/research_reports/RRA2061-5.html. Accessed January 22, 2025.

534 Sergey Radchenko, “Driving a Wedge between China and Russia Won’t Work,” *War on the Rocks* (August 24, 2021), <https://warontherocks.com/2021/08/driving-a-wedge-between-china-and-russia-wont-work/> (accessed January 22, 2025); Jo Inge Bekkevold, “The Beijing-Moscow Axis Is Much Stronger This Time Around,” *Foreign Policy* (October 8, 2024), <https://foreignpolicy.com/2024/10/08/russia-china-axis-alliance-xi-putin-geopolitics/> (accessed January 22, 2025); Angela Stent, “Russia and China: Axis of Revisionists,” *Global China* (February 2020), <https://www.brookings.edu/articles/russia-and-china-axis-of-revisionists/> (accessed January 22, 2025).

know, looking back in a competition can lead one to lose sight of their own goal and focus on the runner ups' advantages, and hence, hurt one's confidence.⁵³⁵ When one looks back, competitors may also take it as a sign that the leader is either getting exhausted or is becoming less confident, which in turn, boosts their own confidence.⁵³⁶

Taking advantage of the time bought by ongoing frictions between Russia and China, the United States and allies can instead try to clarify their own strategic goals, making sure to resolve differences and address conflicting preferences and priorities. Within and across U.S. alliances, competitive dynamics can arise in three ways. Across U.S. alliances in Europe and the Indo-Pacific, this lack of clarity can be particularly destructive because the confrontation of different regional threats can drive states to adopt different threat perceptions and policy preferences. Thus, without clear policies and coordination, allies on each side can end up negating the other's efforts and gains. Within East Asian allies, the same can be said as states regard adversaries in the region with differing level of threat and have different preferences for how best to counter the threat that most concerns them.⁵³⁷ Between the United States and allies, competing priorities can also occur because allies' attention can be trained on countering specific adversaries while the United States has to balance competing priorities and trade-offs across regions. Hence, sorting out differences is key, especially now when there is still time before states are forced to decide on trade-offs at a time when adversaries have succeeded in forging a stronger partnership.

535 Hannah Hartzell, "The Problem with Looking Over Your Shoulder during a Race," *Women's Running* (April 16, 2020). <https://www.womensrunning.com/training/road/problem-looking-over-shoulder-during-race/>. Accessed January 22, 2025.

536 Erick Rheam, "Never Look Back! – Running Life Lesson #10" (June 11, 2013). <https://erickrheam.wordpress.com/2013/06/11/never-look-back-running-life-lesson-10/>. Accessed January 22, 2025.

537 Ross Buchanan, Lesley Kucharski, Anna Péczeli, and Kimberly Peh, *Extended Deterrence in the Indo-Pacific A Regional Track 1.5 Dialogue*, Center for Global Security Research (September 26-27, 2024). https://cgsr.inl.gov/sites/cgsr/files/2024-11/event_report_-_extended_deterrence_in_the_indo-pacific.pdf. Accessed January 22, 2025.

Assurance in an Emerging Technology Environment

Rupal N. Mehta

Introduction

The public discourse in the United States and among its allies, for example, assumes that U.S. extended deterrent capabilities will remain the same despite demands for increasing assurance and strengthening of alliance ties (or the possible expansion of the nuclear umbrella to include additional regions and other key allies) in light of growing adversarial concerns. Yet is this the case? Is it the case that the manner in which the United States manages its defensive alliance commitments in the 21st century will rely on the same set of capabilities, means, and strategy that it employed in the 20th century? In this piece, I focus on this question of how the foundation of extended deterrence may be impacted by the development of new technologies and capabilities that may make the management of defensive commitments easier, or potentially, less credible to allies.

To examine how assurance and credibility are likely to evolve in an environment with emerging technologies, it is first necessary to assess the existing landscape of U.S. defensive commitments. The United States maintains standing diplomatic relations with the vast majority of countries in the international system.⁵³⁸ In a narrower context, the United States has several defense commitments, both multilateral and bilateral agreements, with a broad range of organizations and states in the international community. To date, the United States has a collective defense agreement with the North Atlantic Treaty Organization (NATO) and a host of countries in Latin America under the Rio Treaty, as well as a series of bilateral and trilateral security pacts with Australia and New Zealand, the Philippines, Japan, Taiwan, and South Korea. Lastly, the United States has a long-standing arrangement with Israel that provides a unique degree of military and economic assistance, though it is not legally obligated to aid Israel in the event of an attack.⁵³⁹ Thus, in examining the existing set of U.S. commitments to deter adversaries and assure allies, we can observe that there is a great deal of geographical and obligatory variance.

In the remainder of this chapter, I examine how U.S. commitments to deter and assure is likely to be impacted by the development of new forms of warfighting capabilities, including but not limited to cyber, space, and unmanned drone technology. Specifically, I employ the analogy of a supply and demand market for defense and assess technological innovation that has worked to restructure how patrons and protégés view defensive alliance commitments. Using this framework, I explore how the United States could more effectively leverage its recent development of capabilities to reassure existing allies and potentially consider expansion of its security umbrella to additional allies seeking the deterrent capabilities of the United States. In aggregate, I argue that the introduction of these

538 Neil Narang and Rupal N. Mehta, "The Unforeseen Consequences of Extended Deterrence: Moral Hazard in a Nuclear Protégé," *Journal of Conflict Resolution* 63, no 1 (2019), pp. 218-250. <https://doi.org/10.1177/0022002717729025>. Accessed October 1, 2024.

539 Library of Congress, *HR 932: United States-Israel Strategic Partnership Act of 2013-2014*, (2013-2014). <http://thomas.loc.gov/cgi-bin/query/z?c113:H.R.938>. Accessed October 4, 2024.

emerging technologies may actually help to improve the efficacy of *extending* deterrence while simultaneously making efforts at assuring our allies potentially more challenging. Further, I argue that while emerging technologies may help to reduce the costs and burdens on U.S. forces tasked with navigating multiple potential crises across multiple domains, the use of “intangible” technology may also inadvertently increase the risks that allies feel less assured and are more willing to engage in reckless behavior—potentially entrapping the United States in undesirable conflicts.⁵⁴⁰ These dynamics have important implications for broader questions of grand strategy, peer competition, and developing strategic advantages. I explore these dynamics with an analysis of offensive and defensive cyber capabilities—specifically how the United States has employed these technologies within the U.S.-Japan alliance to help the Japanese counter growing cyber threats from regional adversaries such as China and North Korea. The deployment of cyber cooperation represents a hard case for my theory and should bias against observing a finding, as this technology is non-kinetic and largely “intangible.” Further, it represents an emerging and critical battlefield in this new strategic competitive environment. Lastly, I conclude with a broader policy discussion of how strategies of extended deterrence and the market for multi capabilities-based alliances are likely to continue to shift and evolve and understanding the potentially powerful strategic advantage that emerging technologies may yield will be of critical importance in this increasingly complex and fractious security environment.

New Technologies: Exploring a Supply-Demand Defense Market

The development and deployment of new technologies, including capabilities in the cyber and space domains, and drones or unmanned aerial vehicles, have raised a whole host of new questions about the opportunity and willingness of the United States to fight wars in new theaters against different adversaries in response to emerging capabilities. The introduction of emerging capabilities also has important implications for competition—especially establishing and maintaining a strategic advantage (or favorable position) relative to our competitors that provides an opportunity to shape the international system to benefit our security. As noted in the 2024 National Defense Strategy Commission report, “As U.S. warfighting advantages are eroding in key domains, the United States sorely needs innovative operational concepts that create dilemmas for and impose constraints on adversaries while expanding U.S. options to gain or sustain a competitive edge. Emerging technologies provide new opportunities for such concepts.”⁵⁴¹ Understanding *how* emerging technology is likely to influence the United States’s strategic advantages against its main adversaries will be increasingly important in this evolving two-peer competitor strategic environment.

Further and perhaps more salient for the purposes of this research, given the strategic nature of these interactions, developments in adversarial capabilities to wage war more effectively have a direct and important effect on the nature of extended deterrence and what strategic advantages may be required to combat these new threats and assure allies in the process. Recently, for example, the United States is beginning to face concerns over the strength of its own deterrent capability against

540 Rupal N. Mehta, “Extended Deterrence and Assurance in an Emerging Technology Environment,” *Journal of Strategic Studies* 44, no. 7 (2019), pp. 958–82. doi:10.1080/01402390.2019.1621173. Accessed October 5, 2024.

541 *Commission on the National Defense Strategy Final Report*, RAND (July 29, 2024). <https://www.rand.org/nsrd/projects/NDS-commission.html>. Accessed January 22, 2025.

new threats, such as Russian territorial and cyber challenges against Ukraine including leading up to and after the start of the 2022 invasion of Ukraine. In the first moments of the invasion, Russia launched a cyberattack aimed at disrupting Kyiv’s command and control and ultimately ended up affecting access to a satellite communications network and disrupting internet across Europe.⁵⁴² Simultaneously, the United States is experiencing new risks to cybersecurity from a new generation of non-state actors—self-identified hackers often affiliated with larger non-state organizations. More recent attempts, for example, from the cyber unit of Isil, the Islamic State Hacking Division, to reveal personal identifying information about U.S. military personnel based in the United States and abroad have highlighted potential security concerns in the cyber domain and how they intersect with the more traditional forms of warfighting. Despite these instances from the recent historical record, how these technologies can, and will be employed in conjunction with other forms of technologies and weapons remains an open, critical question for U.S. security.⁵⁴³

Consider, for example, the introduction of new capabilities in the space domain—these concerns are especially salient given the more recent efforts at militarization of space.⁵⁴⁴ As multiple actors, including Russia, China, India, and Israel—the latter two previously absent from the “traditional space race” of the 20th century—join the ranks of having a variety of space assets in position and developing anti-satellite (ASAT) weaponry, new questions emerge about how threats that emerge and develop in space will evolve in response to ground conflict.⁵⁴⁵ As the competition for space continues to grow, an expanding set of countries will continue to contend for technologies that can disrupt, upend, or even destroy their adversaries’ assets both on the ground and potentially even in space. “Enter signal jamming and spoofing, high-powered lasers to dazzle imaging sensors, anti-satellite missiles and spacecraft with the capacity to interfere with others in orbit — counterspace technologies that analysts say leading powers like the United States, Russia, and China could use to target each other’s satellites.”⁵⁴⁶ If, for example, China continues to engage in controversial activities, such as repeated anti-satellite tests since 2007 and the potential threat to U.S. space assets in low earth orbit, how might this impact U.S.-China competition, and even the potential for conflict, in other military domains that may impact our allies’ and partners’ security?⁵⁴⁷

542 Simone McCarthy, “America’s Military Has the Edge in Space. China and Russia are in a Counterspace Race to Disrupt It.” CNN (May 27, 2024). <https://www.cnn.com/2024/05/27/china/counterspace-us-china-russia-intl-hnk-scn/index.html>. Accessed November 25, 2024.

543 Erik Gartzke, “The Myth of Cyberwar: Bringing War in Cyberspace Back Down to Earth,” *International Security* 38, no. 2 (2013), pp. 41–73, <https://direct.mit.edu/isec/article/38/2/41/12093/The-Myth-of-Cyberwar-Bringing-War-in-Cyberspace> (accessed October 7, 2024); Jon Lindsay, “Stuxnet and the Limits of Cyber Warfare,” *Security Studies* 22, no. 3, pp. 365–404. doi: 10.1080/09636412.2013.816122. Accessed October 15, 2024.

544 Center for Global Security Research. *Space and U.S. Defense Strategy Workshop Report* (Livermore, CA: Lawrence Livermore National Laboratory, October 2023). <https://cgsr.llnl.gov/sites/cgsr/files/2024-08/2023-10-Space-Workshop-Bibliography.pdf>. Accessed October 10, 2024.

545 Ibid.

546 Simone McCarthy. “America’s Military Has the Edge in Space. China and Russia are in a Counterspace Race to Disrupt It.” CNN (May 27, 2024). <https://www.cnn.com/2024/05/27/china/counterspace-us-china-russia-intl-hnk-scn/index.html>. Accessed November 25, 2024.

547 Jeffrey Logan, *China’s Space Program: Options for US-China Cooperation*. Congressional Research Service RS22777 (September 29, 2008). <https://sgp.fas.org/crs/row/RS22777.pdf>. Accessed October 14, 2024.

Indeed, these new technologies challenge our theoretical understanding and historical record of effective deterrence, prompting a new set of questions about what counts as deterrence, and extended deterrence, across and between these new domains as the nature of the threat from the adversary continues to evolve and grow. Consider, for example, findings from the Strategic Posture Commission that highlight the necessity for forward-deployed U.S. forces to adequately assure allies and deter foreign aggressor. It states,

U.S. Allies and partners, and the United States itself, deterrence remains the most cost-effective approach to maintain stability. Allies rely on U.S. strategic forces to deter nuclear-armed adversaries. Forward-deployed U.S. forces, coupled with a credible nuclear deterrent, demonstrate that the United States is ready, willing, and able to come to their defense. These assurances and capabilities impact the policies and priorities of those nations who receive U.S. extended deterrence guarantees. For example, many nations have foregone indigenous nuclear weapons programs because of U.S. assurances, underpinned by credible capabilities. These actions demonstrate the confidence Allies and partners place in the United States.⁵⁴⁸

Several questions emerge. Will allies continue to be assured if there is a greater reliance on non-kinetic, non-nuclear deterrents that are not “forward-deployed”? Is it, for example, feasible to employ non-kinetic (neither conventional nor nuclear) means to effectively deter kinetic aggression? In contrast, then, what types of non-kinetic aggression in cyber or space domains would warrant and justify the use of kinetic weapons, such as conventional or nuclear weapons in response? What will escalation—and efforts to deescalate—look like in these domains coupled with emerging technologies? Lastly and most importantly for this study, how will these dynamics operate under nuclear umbrellas where allies continue to seek assurances about the United States' ability and willingness to provide assistance and defense in the event of attack? One core dilemma is that it is often challenging to infer what the discourse actually means. For example, it is quite unlikely that our allies will demarcate exactly what will assure them to avoid drawing a sort of “red line” of extended deterrence commitment.

These questions are of integral importance to U.S. policymakers who are struggling to adapt foreign policy and operational capabilities to consider technological innovation and the wider group of actors that can deploy these capabilities against the United States and its allies in this new, challenging geostrategic environment. And in this environment where the question of “extending” deterrence remains a critical one—especially given ongoing debates about burden sharing, the costs and tradeoffs of alliances, and broader strategic restraint—exploring the role that emerging technologies will play is important.

548 Congressional Commission on Strategic Posture Report, *America's Strategic Posture* (October 2023), pp. 1-160. <https://www.ida.org/research-and-publications/publications/all/a/am/americas-strategic-posture>, Accessed January 22, 2025.

Enhancing Assurance in Extended Deterrence

In this section, I first consider some of the potential benefits of emerging technology in maintaining alliances and providing deterrence to a host of allies. While this logic may be generalizable among the cohort of existing patron states (such as Russia and China), I purposefully focus on the United States's alliance commitments, particularly in the context of the U.S. nuclear umbrella which extends nuclear deterrence over a variety of allied partners. Further, I discuss how these adaptations impact both the United States and its allies as they face increasing evolving challenges in the rapidly changing geostrategic environment.

To make this argument, I adopt the analogy of a supply and demand market for defense. In this market, the United States or another nuclear patron offers to provide or supply defense to an ally asking for protection or assurances against an adversary, and the introduction of new capabilities is likely to fundamentally change how both patrons and protégés view the “price” or “cost” of this assurance. First, the parallel of supply and demand market from macroeconomic theory suggests that a marginal increase in demand requires a higher price (relayed to the consumer or client—in this case, an ally), unless new firms enter the market, or existing firms expand their scale or size. The introduction of emerging technologies may indeed be one such example of the United States working to expand their size and capacity to provide defensive commitments to reduce the costs of these commitments. This is likely to be especially salient with the emergence of potentially less costly additions to force posture, in the domains of cyber and unmanned drone capabilities, that while requiring initial investments in infrastructure, technology, and manpower, do not yield the costs, including loss of human life when used in combat.⁵⁴⁹ If alliance patrons are better able to protect their allies using these technologies in tandem with reductions of other forms of capabilities, it is possible that the overall cost of extended deterrence agreements may actually decrease over time. Further, if, for example, the ability to credibly deter and assure can be primarily accomplished with a combination of integrated deterrent capabilities, particularly with a reliance on some of the less-costly power-projecting emerging technologies, it may also succeed in reducing *domestic* costs on U.S. forces. In this way, deterrence and assurance are collinear—where progress in extending credible deterrence to allies should yield results in whether allies feel adequately assured.

Second, if the United States is able to leverage the intersection between new domains and traditional military domains, such as the interdependence between cyber and drone technology and hard military power, it may appear more credible in its commitments to its allies. The current state of U.S. extended deterrence commitments to NATO/Western Europe has been significantly impacted by a new set of costly challenges (namely recent Russia behavior) and the Obama administration's efforts to steer a U.S. conventional and nuclear “pivot to East Asia.”⁵⁵⁰ Perhaps unsurprisingly, this approach has somewhat oscillated over the past decade during the Trump and Biden administrations. While the Trump administration rolled out a new “Free and Open Indo-Pacific” concept in late 2017 (based on a

549 Julia Macdonald and Jacquelyn Schneider, “Battlefield Responses to New Technologies: View from the Ground on Unmanned Aircraft.” *Security Studies*, 28, no. 2 (2019), pp. 216-249. <https://doi.org/10.1080/09636412.2019.1551565> (accessed October 8, 2024); Julia Macdonald and Jacquelyn Schneider, “Presidential Risk Orientation and Force Employment Decisions: The Case of Unmanned Weaponry,” *Journal of Conflict Resolution*, 61, no. 3 (2017), pp. 511-536, <https://doi.org/10.1177/0022002715590874> (accessed November 4, 2024).

550 Kenneth G. Lieberthal, “The American Pivot to Asia.” Brookings Institution Commentary (December 21, 2011). <https://www.brookings.edu/articles/the-american-pivot-to-asia/>. Accessed November 25, 2024.

term coined by former late Japanese Prime Minister Shinzo Abe) that emphasized the foundation of collective security in the region, this was markedly incongruous with its broader America First strategy that defined the Trump administration's first time and will likely be the cornerstone of the second. In between, the Biden administration's Indo-Pacific Strategy sought to course correct and "underscores the importance of deep and consistent U.S. engagement for advancing U.S. national interests."⁵⁵¹ While consistency often remains across administrations, it is unclear what the second Trump administration is likely to do given its reaffirmation of the principles of the America First strategy and its criticism of alliance frameworks in general.

Given these challenges, the United States has had increasing difficulty assuring its NATO allies (and subsequently its allies in East Asia) about its capacity to adequately defend both regions from their respective adversaries. These competing demands for the United States to project hard military power in two distinct regions simultaneously has only prompted both sets of allies to become less persuaded of the United States's capacity to actually defend them in the event of external aggression (sometimes opting to take matters into their own hands by pursuing indigenous advances in military power). Furthermore, adversaries themselves may be less convinced of the U.S.'s commitment to defend its allies—potentially motivating some aggressors to use this opportunity to provoke allies into disputes when the extent of the U.S. ability to provide adequate defense is uncertain.⁵⁵²

However, it is likely that continuing advances in new cyber, space, and drone technology will advantage the status quo powers, such as the United States, when operating in conjunction with traditional or terrestrial military power. These new technologies create enhanced power-projecting capabilities and allow for a wider menu of strategic options and responses that may signal their alliance commitment more effectively to *both* allies and adversaries. If the United States can demonstrate its commitment to simultaneously deter adversaries and assure allies in multiple regions using a portfolio of means and responses, it may work to reduce uncertainty and provide stability to its allies.

Lastly, emerging cross-domain capabilities may allow the United States to contemplate the extension of the nuclear umbrella to other states and allies.⁵⁵³ In the aftermath of the collapse of the Joint Comprehensive Plan of Action with Iran, other allies have similarly expressed concern about their security and requested further assurances from the United States in the event that Iran successfully acquires nuclear weapons. Over the past few years, defense officials have informally discussed the possible expansion of U.S. military assistance (including the security umbrella more broadly) to concerned allies.⁵⁵⁴ As noted in the scholarship, opening the nuclear umbrella further may

551 Carla Freeman, Mirna Galic, Daniel Markey, and Vikram J. Singh, *Two Years Later, What Has the Indo-Pacific Strategy Achieved?* United States Institute for Peace Analysis (February 15, 2024). <https://www.usip.org/publications/2024/02/two-years-later-what-has-indo-pacific-strategy-achieved>. Accessed January 21, 2025.

552 Matthew Fuhrmann and Todd S. Sechser, "Signaling Alliance Commitments: Hand-Tying and Sunk Costs in Extended Nuclear Deterrence." *American Journal of Political Science* 58, no. 4 (2014), pp. 919-935. <https://doi.org/10.1111/ajps.12082>. Accessed October 15, 2024.

553 Jennifer Bradley, *Preventing the Nuclear Jungle: Extended Deterrence, Assurance, and Nonproliferation*. Joint Force Quarterly 112, pp. 1-6. <https://ndupress.ndu.edu/Media/News/News-Article-View/Article/3679143/preventing-the-nuclear-jungle-extended-deterrence-assurance-and-nonproliferation/>. Accessed November 25, 2024.

554 Congressional Research Service, *U.S. Extended Deterrence and Regional Nuclear Capabilities* (August 8, 2024). <https://crsreports.congress.gov/product/pdf/IF/IF12735>. Accessed November 25, 2024.

also work to prevent these states from increasing their conventional military power and potential indigenous nuclear proliferation.⁵⁵⁵ A formalized security guarantee with a series of reliability-enhancing provisions may limit the perverse side effect of alliances by limiting potential moral hazard among allies.⁵⁵⁶ It may also prevent allies from seeking assurances from other major powers—a move that could further destabilize efforts at strategic stability and upset the two peer competitor balance. Consider this dynamic in the context of “price” (the costs of supplying defense and protection to alliances) and quantity (the maintenance of the nuclear umbrella). Nuclear patrons such as the United States may be incentivized to just absorb the savings produced by cost reductions stemming from emerging technology; at the same time, nonproliferation aims may encourage these patrons to extend defensive agreements to prevent allies from acquiring other, potentially destabilizing capabilities.⁵⁵⁷ Thus, as the “price” of defense drops, we may start to see some interesting effects with regard to supply and demand.

Specifically, based on this model, we may expect reducing the price of alliances, through the addition of cheaper emerging technologies, may increase the supply of alliances (thus increasing the number of states protecting by the alliance or the degree to which they are protected)—despite the potential inclination to simply recoup the savings.⁵⁵⁸

Thus, despite supply constraints in the ability to provide protection of allies and defend U.S. territory, demand for U.S. protection has only increased with the emergence of new challenges and threats to international security. Yet, given the existing limitations on U.S. forces, it has been difficult to imagine the United States supplying formal security guarantees to even more states in the international community. New capabilities that allow the United States to expand its global presence without continuing to strain its conventional and nuclear forces may provide an opportunity for the U.S. to extend the security umbrella. If the United States can deploy a range of emerging technologies in the cyber, space, unmanned vehicle, or artificial intelligence (AI) domains that reduces the emphasis on traditional military, warfighting power, it may be able to provide more convincing assurances to a broader set of allies, and send important, costly signals to adversaries, without dramatically increasing the cost to do so.

555 Gene Gerzhoy, “Alliance Coercion and Nuclear Restraint: How the United States Thwarted West Germany’s Nuclear Ambitions,” *International Security* 39, no. 4 (Spring 2015), pp. 91–129, <https://www.jstor.org/stable/24480608> (accessed November 8 2024); Rupal N. Mehta, *The Politics of Nuclear Reversal* (New York, NY: Oxford University Press 2020); Jeffrey WKnopf, “Varieties of Assurance,” *Journal of Strategic Studies* 35, no. 3 (2012), pp. 375–399, <https://doi.org/10.1080/01402390.2011.643567> (accessed October 4, 2024).

556 Neil Narang and Rupal N. Mehta, *The Patron’s Dilemma: Recklessness and Restraint under Nuclear Umbrellas* (book manuscript in progress, 2025).

557 Ibid.

558 Rupal N. Mehta, “Extended Deterrence and Assurance in an Emerging Technology Environment,” in *Emerging Technologies and International Stability*, Todd S. Sechser, Neil Narang, and Caitlin Talmadge, eds. (London: Routledge, 2021). <https://www.taylorfrancis.com/chapters/edit/10.4324/9781003179917-4/extended-deterrence-assurance-emerging-technology-environment-rupal-mehta>. Accessed October 14, 2025.

Producing Instability in Extended Deterrence

However, it is important to note that the market for extended deterrence may not always operate this way and the emergence of cross-domain capabilities may differentially present some challenges or weaknesses to alliance commitments, or certain sets of allies in the international system. Consider, for example during the Cold War, the introduction of intercontinental ballistic missiles (ICBMs) capable of delivering nuclear weapons across the world, without requiring forward deploying basing and personnel on allied territory, altered the way that both allies and the United States viewed their ability to protect allied territory. Kegler and Raymond argue,

European members of NATO in particular began to question whether the United States would, as it had pledged, protect Paris or Bonn by sacrificing New York. Under what conditions might Washington or Moscow be willing to risk a nuclear holocaust. The uncertainty became pronounced while the pledge to protect allies through extended deterrence seemed increasingly insincere.⁵⁵⁹

An increasing reliance on these mobile assets, such as ICBMs, that didn't require the same degree of costly infrastructure as forward-deployed conventional forces or military personnel raised doubts about the credibility of the U.S. commitment. And despite consistent efforts to assure, it was challenging to convince allies in Europe and East Asia that the United States would be willing to undertake action that could potentially risk the security of the United States.

What does this look like in the realm of emerging technologies? How is this costly trade-off likely to operate in an integrated deterrence world where an act of aggression, potentially a provocation of war, may begin in a non-kinetic domain? For example, would the United States be willing to defend an ally if the dispute begins in cyberspace? While allies are likely to want a generous and open interpretation of provocation to encourage action from the United States, it is not clear the extent to which the United States would actually be willing to “risk New York for Paris” and respond with appropriate force if an ally is attacked with a cyber weapon. And even if the United States may be willing to do that, would it be able to *credibly* convey that to both the ally and the adversary to ensure the broader deterrence effect? If the threshold or “redline” for a U.S. military response is uncertain in the most traditional of security environments, the manner in which extended deterrence is likely to operate in a new multi-theater, emerging technology environment is likely to be even more complex. No doubt there is variance in the types of emerging technologies that may be extended even within a specific domain—for example, there are critical differences between sharing cyber exploits compared to the building of centers of excellence or other forms of concrete, visible cooperation that is likely to influence *how* assured allies really feel.⁵⁶⁰

Secondly, these concerns are likely to become even more salient with new forms of emerging capabilities that can be easily moved and used elsewhere. As Gartzke notes, “Submarines—

559 Charles Kegler and Gregory Raymond, *The Global Future: A Brief Introduction to World Politics* (Boston, MA: Cengage Learning, 2010), pp. 1-128.

560 Erik Lin-Greenberg, “Evaluating Escalation: Conceptualizing Escalation in an Era of Emerging Military Technologies,” *Journal of Politics*, 85, no. 3 (2023), pp. 1-11. <https://doi.org/10.1086/723974>. Accessed October 8, 2024.

emblematic of stealth—should be better at projecting power than at exerting influence, also leading to increased uncertainty about the intensity or permanence of national interests.”⁵⁶¹

Conveying costly signaling was a challenge when considering the positioning of submarines, aircraft carriers, or other mobile but discrete assets.⁵⁶² It is even more difficult to assess how the “deployment” of cyber or artificial intelligence technology (that faces quite different constraints in deployment or operational use) in defense of an ally will impact their perception of U.S. permanence and commitment to deter foreign aggressors.⁵⁶³ Patrons may need to consider the signal being sent to allies when they implement cheaper and easier means of providing security. Consider the role of AI in “enhance[ed] international and industry collaboration with foreign partners and allies” as noted in President Trump’s 2019 Executive Order.⁵⁶⁴ Operationally, AI may actually “complicate burden-sharing and the interoperability of alliance military forces” and potentially present insurmountable obstacles to decisionmaking due to misinformation and mistrust.⁵⁶⁵ As with existing military technologies, emerging technologies may present costly tradeoffs that complicate strategies of extended deterrence and could perversely destabilize already tense regional environments.

Lastly, some states have begun to mirror investment in similar, new types of technology to counteract the emergence of integrated deterrence capabilities that can be used between patrons and their client states. By highlighting weaknesses in defensive alliance commitments, some states have started to develop “puncture” capabilities that are low cost, high technology and highly effective means of countering development in extended deterrence. In the case of China, for example, the People’s Liberation Army (PLA) is beginning to establish “new-type combat forces” that merge naval aviation, cyber, and special forces to adapt to changing demands for combat readiness and military doctrine to more effectively counter U.S. assets in the region.⁵⁶⁶ Additionally, China has begun to use “low-intensity coercion” to advance its maritime objectives in the East and South China Seas—often threatening U.S. allies in the region, including the Philippines and Japan.⁵⁶⁷ These efforts suggest that “China often uses a progression of small, incremental steps to increase its effective control over

561 Erik Gartzke and Jon R. Lindsay, “The Influence of Sea Power on Politics: Domain- and Platform-Specific Attributes of Material Capabilities,” *Security Studies* 48, no. 4 (2020), pp. 601–636. <https://www.tandfonline.com/doi/abs/10.1080/09636412.2020.1811450>.

562 Center for Global Security Research, “Toward a New Division of Labor Between and Among the United States and its Allies and Partners,” Workshop Report (Livermore, CA: Lawrence Livermore National Laboratory, June 2023). <https://cgsr.llnl.gov/sites/cgsr/files/2024-08/CGSR-Workshop-Summary-2023-06.pdf>.

563 Erik Lin-Greenberg, “Allies and Artificial Intelligence: Obstacles to Operations and Decision-Making,” *Texas National Security Review* 3, no. 2, pp. 56-72. <https://tnsr.org/2020/03/allies-and-artificial-intelligence-obstacles-to-operations-and-decision-making/>. Accessed October 15, 2024.

564 Donald J. Trump, “Executive Order on Maintaining American Leadership in Artificial Intelligence,” The White House (February 11, 2019). <https://www.whitehouse.gov/presidential-actions/executive-order-maintaining-american-leadership-artificial-intelligence/>. Accessed December 8, 2024.

565 Erik Lin-Greenberg, “Allies and Artificial Intelligence: Obstacles to Operations and Decision-Making,” *Texas National Security Review* 3, no. 2, pp. 56-72. <https://tnsr.org/2020/03/allies-and-artificial-intelligence-obstacles-to-operations-and-decision-making/>. Accessed October 15, 2024.

566 Office of the Secretary of Defense, *2018 Nuclear Posture Review*. RefID: 2001872886.

567 Elliott Brennan, *South China Sea: Beijing’s Low-Intensity Coercion and Southeast Asia’s Response*. Lowy Institute (May 14, 2015). <https://www.lowyinstitute.org/the-interpreter/south-china-sea-beijing-s-low-intensity-coercion-southeast-asia-s-response>. Accessed November 25, 2024.

disputed territories and avoid escalation to military conflict.”⁵⁶⁸ While these moves are made to increase China’s presence and control over disputed islands in the region, their strategy regarding escalation control—and avoiding conflict with the United States—remains unknown.

China’s military modernization program, which includes advances in the PLA’s Air Force (already the third largest in the world), also includes development on new technologies in the unmanned aerial vehicles (UAVs) and space and counterspace domains. China’s focus on satellite communication, intelligence/surveillance/reconnaissance (ISR), and satellite navigation is primarily aimed at responding to the U.S. superiority in space and, potentially, other terrestrial domains. A recent PLA analysis of United States and coalition military operations states, “destroying or capturing satellites and other sensors...will deprive an opponent of initiative on the battlefield and [make it difficult] for them to bring their precision-guided weapons into full play.”⁵⁶⁹ For example, China appears to recognize that one way to respond to the U.S. supremacy in other key kinetic domains (especially with regard to the United States’s extension of a security umbrella to some of China’s adversaries) is to develop technologies that counteract the utility of the U.S.’s cross-domain, emerging capabilities for extended deterrence.

In aggregate, this type of technological “arms-racing” among emerging technologies beyond the kinetic realm—especially as adversaries develop new capabilities to counteract innovations in the U.S. security umbrella—may produce some unforeseen, and potentially destabilizing, consequences. It could be that extended deterrence in an emerging technology world operates similarly: adversaries are still hesitant to escalate conflicts that may require the involvement of the patron, and clients are more likely to avoid conflict but gain some political benefits or concessions by the presence of their patron.⁵⁷⁰

Furthermore, the emergence of new capabilities that reduces the cost of U.S. power projection and allows the United States to operate in multiple theaters to defend allies simultaneously may be a more useful avenue for assuring existing, and future, allies of the credibility of the United States’s commitment. Alternatively, it could be that the vulnerabilities increasing in a cross-domain world may not adequately deter adversaries from attacking client states. How the inclusion of multiple, intersecting capabilities will more efficiently or effectively defend a protégé from attack remains an open critical question for the future of integrated, extended deterrence.

Finally, it is important to assess how these technologies may actually change the nature of conflict. Innovations and lower barriers to entry may then prompt states to be more willing to engage in low levels of destabilizing behavior, potentially even conflict to achieve their aims or change the status quo. For example, as I have argued elsewhere:

568 Ibid.

569 Office of the Secretary of Defense, *Nuclear Posture Review* (January 1, 2018), pp. 1-100. <https://media.defense.gov/2018/feb/02/2001872886/-1/-1/1/2018-nuclear-posture-review-final-report.pdf>. Accessed December 13, 2024.

570 Matthew Fuhrmann and Todd S. Sechser, “Signaling Alliance Commitments: Hand-Tying and Sunk Costs in Extended Nuclear Deterrence,” *American Journal of Political Science* 58, no. 4 (2014), pp. 919-935, <https://doi.org/10.1111/ajps.12082> (accessed October 15, 2024); Neil Narang and Rupal N. Mehta, “The Unforeseen Consequences of Extended Deterrence: Moral Hazard in a Nuclear Protégé,” *Journal of Conflict Resolution* 63, no. 1 (2019), pp. 218-250, <https://doi.org/10.1177/0022002717729025> (accessed October 1, 2024); Brett V. Benson, Adam Meirowitz, and Kris Ramsay, “Inducing Deterrence Through Moral Hazard in Alliance Contracts,” *Journal of Conflict Resolution* 58, no. 2 (2014), pp. 307-335. <https://www.jstor.org/stable/24545640>. Accessed November 13, 2024.

It is similarly important to note that the emergence of these technologies or other technology innovations may actually make high-scale conflict less likely. As the barrier to entry in the extended deterrence market is lowered, potential patrons may not be willing to use developing technologies or smaller-scale military innovation to challenge other states in the international system for fear of escalation. The addition of these technologies also highlight concerns in escalation management—namely how new technologies rank on the escalation ladder and types of de-escalatory measures.⁵⁷¹

These discussions yield several important implications for policymakers. Allies may seek greater assurance or potentially be emboldened to seek to challenge adversaries on their own—potentially engaging in costly and reckless moral hazard.⁵⁷² These risks are especially salient in these types of asymmetric alliances as allies may be susceptible to inadvertent escalation due to being new members of an alliance that do not necessarily have the same experience thinking about and practicing escalation management as do their patron states. Allies may even begin to develop or deploy their own technology that provides independence from their patrons to challenge adversaries.⁵⁷³ As a result, in the absence of some of the core motivating factors behind alliances such as capability aggregation and security through substitution, the value of alliances for allies (or their patrons) could dramatically decline. Lastly, it is also possible that allies may seek assurances elsewhere and turn to other major powers for another security partnership.

Thus, in aggregate, this logic suggests a duality to the effects of emerging technology in extended deterrence: while it may improve patrons' ability to actually defend their allies, these allies, in turn, may be incentivized to look elsewhere for assurances that they deem to be more credible, whether through the pursuit of indigenous capabilities or alternative partners.

Case Exploration: Cyber Capability in the U.S.-Japan Alliance

To illustrate these dynamics, I explore a brief case study of the role of cyber capabilities in the United States-Japan relationship. Japan maintains a formal extended deterrent agreement with the United States, the Treaty of Mutual Cooperation and Security between the United States and Japan which establishes a military commitment to defend one another and ostensibly puts Japan under the protection of the U.S. nuclear umbrella.

However, given the increasing number and scale of threats that Japan faces—from China, North Korea, and even Russia—Tokyo has continued to seek assurances from the United States that it will provide adequate defense if needed. As noted in a recent set of remarks by a Defense Department official,

571 Mehta, "Extended Deterrence and Assurance in an Emerging Technology Environment."

572 Neil Narang and Rupal N. Mehta, "The Unforeseen Consequences of Extended Deterrence: Moral Hazard in a Nuclear Protégé," *Journal of Conflict Resolution* 63, no. 1 (2019), pp. 218-250. <https://doi.org/10.1177/0022002717729025>.

573 Rupal N. Mehta, *The Politics of Nuclear Reversal* (New York, NY: Oxford University Press 2020); Rupal N. Mehta, "Extended Deterrence and Assurance in an Emerging Technology Environment," *Journal of Strategic Studies* 4, no. 7 (2019), pp. 958-982. <https://doi.org/10.1080/01402390.2019.1621173>. Accessed October 8, 2024.

The regional security landscape is heavily impacted by China's rapid military modernization, increasing provocations abroad, and comprehensive repression at home. The combination of emerging capability, operational activity, and routine dismissal of regional and global norms cannot be explained as simply defensive in nature. We have surpassed any reasonable explanation that China's intent is benign. Rather, these developments reflect an unyielding ambition to rewrite the international code that has delivered prosperity and security to this region over the past eight decades.⁵⁷⁴

Yet, the United States similarly is facing increasing demands for assurance from a wide range of allies across the world. To face these challenges, the United States has begun to rely on additional, emerging technologies to provide assurance to key allies and shore up their defensive commitment in light of continued adversarial aggression, especially in non-kinetic domains such as cyberspace. Japan, for example, has seen a significant rise in cyberattacks from foreign nations over the past few years. As analysts note,

According to Japan's National Police Agency (NPA), there were about 7,800 cyberattack cases in Japan from foreign nations in the first half of 2022, which was double the number of cases in 2019. There also was a surge in cyberattacks against Japanese companies and government offices from March 2023 up to the May 2023 Group of Seven summit hosted in Japan.⁵⁷⁵

The targets ranged from critical infrastructure to local governments, as well as firms in the private sector. Further, since 2017, Japan has lost nearly \$750 million in cryptocurrency; hackers from North Korea are the largest originating source for those cyberattacks.⁵⁷⁶ This surge in attacks has prompted a renewed focus, in government, policy, and public dialogues, about how to develop a new strategy to address these challenges.

And indeed, the resulting 2022 National Security Strategy (NSS) highlighted these concerns and argued for a greater national security cybersecurity agenda to enhance active cyber defense. As reflected in the document,

The 2022 NSS called for the government to strengthen its ability to analyze and aggregate the situation on disinformation, use of artificial intelligence (AI) to

574 Jed Royal, *Remarks by Principal Deputy Secretary of Defense for Indo-Pacific Security Affairs Jed Royal at the 2024 Mt. Fuji Dialogue* (November 18, 2024). <https://www.defense.gov/News/Speeches/Speech/Article/3968062/remarks-by-principal-deputy-secretary-of-defense-for-indo-pacific-security-affa/>. Accessed November 25, 2024.

575 Greg Rattray and Seungmin Lee, *U.S. – Japan Cyber Cooperation: Meeting Challenges and Operationalizing Opportunities*, Weatherhead East Asian Institute Report (December 2023). https://weai.columbia.edu/sites/default/files/content/pics/JRP/Rattray_Lee_US_Japan_CyberCoop.pdf (accessed December 14, 2024); Mark Bryan Manantan, Emily Goldman, Mihoko Matsubara, Benjamin Bartlett, Andrew L. John, and Mina Takazawa, *U.S.-Japan: Advancing Cybersecurity and Resiliency in the Age of Uncertainty*, Pacific Forum International (February 20 2024), <https://pacforum.org/publications/us-japan-advancing-cybersecurity-and-resiliency-in-the-age-of-uncertainty/> (accessed October 8, 2024).

576 Ibid.

enhance monitoring of the information space, and restructure the Cabinet’s National Center for Incident Readiness and Strategy for Cybersecurity (NISC) to coordinate cybersecurity policies with Japan’s Self-Defense Force’s (JSDF) and the police’s cyber units. The MoD [Ministry of Defense] plans to train 4,000 cyber “warriors” and 16,000 JSDF personnel in cybersecurity in five years. Over the next five years, Japan also plans to spend \$58 billion for cybersecurity and space defense.⁵⁷⁷

Importantly, this call for renewed resources and focus comes alongside a request to strengthen cybersecurity cooperation with the United States. Indeed, this objective was specifically highlighted within the NSS—namely, asking for great U.S. support for Japan’s new cyber effort in the aftermath of the early lessons learned from the Ukraine conflict in 2022. The United States has responded with demonstrating greater interest and emphasis on cyber cooperation, including with high level visits from senior national security advisors, such as the deputy national security advisor for Cyber and Emerging Technology and the U.S. cyber director, who have warned about the challenges posed by Chinese state hackers attacking Japanese defense networks and shared “the U.S. government’s upcoming national cybersecurity strategy seeking to enhance synergies between the two national cyber strategies.”⁵⁷⁸

This request suggests that allies, like Japan, are searching for additional avenues of assurance—including through emerging technologies—to address new and pressing challenges across a range of domains.⁵⁷⁹ As allies continue to face these threats, the United States is also working to identify means by which to provide the necessary assurance and support to allies without taxing the United States’s broader extended deterrent commitments. As a result, the United States has sought alternative means of providing this assistance, including through efforts to “increase operational collaboration, enhance security of industrial control systems, deepen capacity building for the Indo-Pacific Region, and establish an ongoing dialogue.”⁵⁸⁰ One hallmark of this effort was the September 2023 Joint Cybersecurity Advisory from the U.S. Cybersecurity and Infrastructure Security Agency, the U.S. National Security Agency, and the Federal Bureau of Investigation (FBI), alongside Japanese agency partners such as Japan’s NPA and NISC.⁵⁸¹ This cooperative effort, which mirrors the United States’s own concepts of “Defending Forward” and “Persistent Engagement,” has focused on Chinese cyber activity that has largely targeted Japanese government, industry, technology, and defense

577 Mark Bryan Manantan, Emily Goldman, Mihoko Matsubara, Benjamin Bartlett, Andrew L. John, and Mina Takazawa, *U.S.-Japan: Advancing Cybersecurity and Resiliency in the Age of Uncertainty*. Pacific Forum International (February 20, 2024). <https://pacforum.org/publications/us-japan-advancing-cybersecurity-and-resiliency-in-the-age-of-uncertainty/>. Accessed October 8, 2024.

578 Ibid.

579 Yukio Satoh, *U.S. Extended Deterrence and Japan’s Security* (Livermore, CA: Center for Global Security Research, 2017). <https://cgsr.llnl.gov/sites/cgsr/files/2024-08/satoh-report-final.pdf>. Accessed December 1, 2024.

580 Ibid.

581 Ibid.

industrial base assets.⁵⁸² Part of this endeavor also includes updating Japan’s cyber posture and force structure to navigate these challenges in cyberspace and enhance extended deterrence. As noted by some analysts,

As the NSS seeks to upgrade JSDF [Japan Self-Defense Force]’s cyber defenses to be on par with its Western counterparts, the goal is for Japan to become well-positioned in monitoring and attributing cyberattacks and launching countermeasures. Japan’s move toward active cyber defense points to a stronger trajectory of U.S.-Japan cybersecurity cooperation. The upgrade is indeed vital to bolster the U.S.-Japan’s alliance’s capacity to adapt and operate in the multidomain environment.⁵⁸³

There is still work to do. For example, it will be necessary for Japan and the United States to undertake some additional effort, including establishing a joint steering committee to strengthen combined U.S.-Japanese operational capabilities with U.S. forces and JSDF, collaboration on training and exercise, and renew efforts with the private sector. Some research also suggests Japan will similarly need to undertake some action at home to improve the efficacy of the joint U.S.-Japan extended deterrent efforts in cyberspace, including increased and consistent information sharing with the United States and Five Eyes partners and strengthening Japanese “threat hunting” capabilities, including training 4,000 cyber “warriors” in the Ministry of Defense to work alongside JSDF personnel to search for and mitigate adversarial attacks.⁵⁸⁴ These adaptations highlight new contributions to burden sharing within the alliance and are a useful example (of the logic explored above) of how emerging technologies, especially joint efforts between patron and ally, may help to alleviate some of the costs of extended deterrence.

However, as my theory suggests, there may also be some underexplored risks associated with the use of emerging technologies to actually extend deterrent benefits in these security partnerships. In addition to challenges to interoperability and burden sharing, there is also the possibility that allied states, feeling less assured, may become emboldened to take matters into their own hands, and engage in behavior that is more reckless or risk-acceptant than their nuclear patrons may want.⁵⁸⁵ This behavior may be the result of a host of factors facing the broader global security environment: China’s increasing aggressive behavior in the Taiwan Straits and the South China Sea, intensifying North Korean missile provocation, and Russia’s full-scale invasion of Ukraine in 2022. These changes

582 Mark Bryan Manantan, Emily Goldman, Mihoko Matsubara, Benjamin Bartlett, Andrew L. John, and Mina Takazawa, *U.S.-Japan: Advancing Cybersecurity and Resiliency in the Age of Uncertainty*, Pacific Forum International (February 20, 2024). <https://pacforum.org/publications/us-japan-advancing-cybersecurity-and-resiliency-in-the-age-of-uncertainty/>. Accessed October 8, 2024.

583 Ibid.

584 Greg Rattray and Seungmin Lee, *U.S. – Japan Cyber Cooperation: Meeting Challenges and Operationalizing Opportunities*, Weatherhead East Asian Institute Report (December 2023). https://weai.columbia.edu/sites/default/files/content/pics/JRP/Rattray_Lee_US_Japan_CyberCoop.pdf. Accessed December 14, 2024.

585 Neil Narang and Rupal N. Mehta, “The Unforeseen Consequences of Extended Deterrence: Moral Hazard in a Nuclear Protégé,” *Journal of Conflict Resolution* 63, no. 1 (2019), pp. 218-250. <https://doi.org/10.1177/0022002717729025>. Accessed October 1, 2024.

and the growing set of challenges that Japan has been facing across a range of domains have fueled transformation in the Japanese psyche about providing for its own defense. As noted by some analysts,

More importantly, Japan realized that it needs to develop the means to defend itself effectively from external aggression. Russia's failure to secure an immediate victory over Ukraine, due in large part to weak supply lines and logistical capabilities, heightened Japan's concern about the lack of investments in its own logistical capacity and, even more acutely, in the resiliency of the Japan Self-Defense Force.⁵⁸⁶

This shift in policy upends decades of Japan's postwar security policy. These new commitments to increase (nearly double) defense spending and acquire counterstrike capabilities to meet these new multidomain challenges suggests a marked change from the postwar strategy of "possessing just enough defensive capability to prevent a power vacuum from emerging in East Asia to one that aims to respond to specific threats."⁵⁸⁷ That shift was also the result of what Tokyo perceived as volatility in U.S. foreign policy over the past decade. As a seasoned Japanese observer of U.S. foreign policy put it, "[I]f it turns out that what we saw during the [Trump administration] is not an anomaly but rather can easily come back in the future, we really ought to start thinking about 'Plan B,' which is a world where Japan may not be able to count" on the United States.⁵⁸⁸

This uncertainty has put Japan on an uncharted path to acquire new capabilities that would have been seen as unimaginable nearly a decade ago. In addition to defense-related spending, as noted above, across a range of domains, including cyber, Tokyo has begun to promote an all hands on deck, integrated, all-government approach to effectively countering threats across military, economic, space, and cybersecurity domains. It has also sought to blur the lines between what is considered an "offensive" or "defensive" capability and what is strictly for military use, versus dual-use technologies that can traverse between civilian and security applications. As further evidence of Japan's increasing emboldenment, Tokyo has also had a parallel shift in posture, including changes to its perspective on preemptive first strike, suggesting that "it would not be unconstitutional to strike an enemy launch pad or base before a missile launch, instead of waiting for the missile's booster phase."⁵⁸⁹ This represents a significant shift in favor of a more offense-oriented defensive posture than has been seen before. In addition, Japan has sought additional opportunities to play a much bigger role in the decisionmaking process, including part of the chain of command. As part of the benefits of interoperability, Japan continues to assert its influence in strategies about retaliation, defensive capabilities, and even preemptive action.

586 Yuki Tatsumi, *Japan's Shift to a More Robust Self-Defense Policy*. Arms Control Today (June 2023). <https://www.armscontrol.org/act/2023-06/features/japans-shift-more-robust-self-defense-policy>. Accessed November 25, 2024.

587 Ibid.

588 Ibid.

589 Darlene Onuroah, "Is Japan's Defense Policy Taking an Offensive Turn," *International Affairs Review* (September 9, 2024). <https://www.iar-gwu.org/blog/oo6h3mo5qy895akjv83zgwudjh38n2>. Accessed November 25, 2024.

In sum, this brief case analysis of the U.S.-Japan alliance reveals the marked shifts in the nature of extended deterrence today and what we may expect from allies in the future. As threats compound and the supply of capabilities to deter and defend against those threats comes further in doubt, the United States has sought opportunities to ease some of the burdens of these alliances through emerging technologies that can address a new range of multidomain threats. However, as this cooperation has increased, so too have efforts from allies to leverage the complexities of the strategic environment to pursue their own, more forceful objectives in light of what may be a new era of extended deterrence.

Concluding Remarks

The geopolitical environment has evolved dramatically since the end of the Cold War. Changes in the number and nature of superpowers, theaters for operation and combat, alliances and adversaries, and posture and doctrines have influenced how the United States sees its commitments to other states in the international system. In this chapter, I analyze how these changes, specifically the evolution of U.S. military forces during the Cold War, provide a useful backdrop and foundation for assessing how emerging technologies may impact how the United States can work to deter adversaries and assure its allies in the international community. Specifically, I provide a logic for how these emerging capabilities may alter the dynamic between nuclear patrons, like the United States, and their protégés. While the analogy of the diversification of U.S. nuclear forces would suggest that the integrated deterrence capabilities could allow for more efficient and less-costly power projection, the inherent vulnerabilities of a multi-domain, multi-theater security umbrella may significantly challenge the United States's ability to effectively deter conflict or provide defense for their protégé states.

I explored these dynamics in a brief case illustration of new and intensifying cyber challenges facing the U.S.-Japan alliance. Given the rise in threats that Japan has been facing across domains and from a range of actors, it has turned to the United States to help provide some assurance and defensive tools to navigate these adversarial challenges. As part of the U.S.'s extended deterrent commitment to Japan, the United States has leveraged its own capabilities in the cyber domain to provide tools for the Japanese to navigate these new waters and work to develop a new set of capabilities that can meet the threat and begin to more actively deter potential attacks. But this evolution in capability has also come with some increasingly aggressive behavior by Japan to enhance their indigenous capabilities and declare changes in policy.

Primarily, I have focused on assessing these dynamics for the United States and its allies in the international system. However, one may ask how the introduction of cross-domain capabilities influences a broader set of patron/protégé relations. Indeed, a multi-domain extended deterrent universe raises several important implications and questions for the future. Will the development of emerging technologies reduce the barriers to entry in the security umbrella market and reduce the demand for nuclear patrons in general if more states are able to acquire indigenous capabilities to use for their own deterrence? Alternatively, are we, for example, likely to see new regional powers like China and India take on a greater role in security partnerships in their regions by pursuing the development of the necessary capabilities and force posture to adequately do so? If these or other states can establish superiority or primacy in certain forms of extended deterrent capabilities, how does this impact the desire for the United States to provide assurances and protection to a wide array

of allies? Lastly, will the deployment of these emerging technologies to our allies make the possibility of conflict more likely?

Secondly, this discussion suggests that there are likely to be some critical implications for defensive alliance commitments themselves. If, for example, we focus on the demand side of the equation, this research may imply that the addition of more capabilities that allow the United States to increase their global presence and project power to multiple theaters credibly may increase the nature of the demands for assurance that allies place on the United States. Similarly, the existing alliances may serve as a precedent for other states to seek the benefits of the U.S. alliance. If the full force of the U.S. military establishment can be in multiple places at once, states may seek to move from informal alliance commitments to formal and legal defense pacts that provide greater assurances that if attacked, there would be a U.S. conventional, and potentially nuclear, response.

Finally, it may also be the case that the United States will have to carefully attune its foreign policy to address these changing demands. If some of the emerging, integrated deterrence capabilities are more favored by allies over others, the United States may need to consider adapting its force structure to accommodate alliance concerns and include some of these technologies. With this changing calculus underlying the decisionmaking behind extended deterrence, demands for deterrence and assurance are likely to evolve in the ever-evolving geo-political environment.

There is little doubt that extended deterrence and assurance are going to continue to look quite different in the next phase of the 21st century than it did in the 20th century, and it will increasingly be important to capitalize on these changes to ensure that the United States maintains its strategic advantages across a host of domains. It is likely that the old models of physical tripwires through boots on the ground or even large-scale military and economic assistance may evolve or shift over time, but the evidence suggests that a little bit of technology may actually go quite a long way in terms of providing the necessary assurances to our allies about the strength of the U.S. commitment. Indeed, the inclusion of emerging technologies into broader strategic thinking and new models of U.S. force structure may yield some important insights into the tradeoffs involving minimum expenditure for maximum payoff, especially given the key role that the United States has (and will continue to) play as a technological incubator for sharing advanced technologies with our allies. Leveraging these developments and thinking more concretely about where the United States can pursue its comparative, strategic advantage through emerging technologies and where our allies may be able to complement these efforts through alliances will have important implications for strategic stability and broader competition with peers and near-peer powers. To wit, while some of our answers get more complicated in the context of extended deterrence in the world of increasing technology competition, there remains significant opportunity to lower the specter of conflict and search for avenues for peace.

Adaptation Advantage

Dustin League

Introduction

“Success no longer goes to the country that develops a new technology first, but rather to the one that better integrates it and adapts its way of fighting.”⁵⁹⁰

– 2018 U.S. National Defense Strategy

Gary Kasparov holds an overwhelming strategic advantage against the average player in the game of chess despite both players having identical resources on the board. Kasparov’s advantage is not based on any asymmetry in the game or because he has more advanced pieces to use. Instead, his advantage comes from being able to use his pieces far more effectively than his opponent will. Barring fluke accidents or cheating, Kasparov will certainly win in the vast majority of games. Now imagine a series of chess games where new capabilities are introduced into play at the start of a game, for instance by adding new move sets to pieces (rooks can now hop other pieces like knights or pawns can move backwards). The player with access to those new move-sets gains advantage, maybe enough to make up for Kasparov’s talent and experience, maybe not. Now, allow the new capabilities to carry forward into subsequent games, but Kasparov can also use the new movements. Who holds the advantage? Advantage may swing to the amateur in a particular game if a new move-set is particularly powerful, but over time Kasparov is far more likely to win more than he loses.

Chess is a simple wargame, one that is designed to be balanced. While this nature prevents it from capturing the real-world asymmetries between parties involved in armed conflict, the game readily highlights one crucial aspect: *skill matters*. Capabilities confer advantages, but the skillful employment of those capabilities matters more. Advantages based on capabilities can also prove short lived; they can be replicated, stolen, or rendered obsolete. In the imaginary series of chess games, there should be no doubt that Kasparov’s deeper knowledge of chess, his long experience playing fierce opponents and learning how to react and counter their strategies and tactics, will give him the long-term advantage. Kasparov may lose a game or two whenever some new move-set creates a dramatic enough change in the game, but he will adapt and overcome, finding a better way to fit the new movements into his play over the series. A skillful player is one who can learn quickly how to incorporate new moves and new capabilities into their concept of the game and understand how their play needs to change to accommodate those capabilities.

The promise of so many technological innovations is an increase in military effectiveness, and many do so up until an adversary learns how to defeat them. Technological advantage alone is not sufficient for strategic advantage in the long run. Militaries need to be ready to adopt technological

590 U.S. Department of Defense, “Summary of the 2018 National Defense Strategy of the United States of America” (Washington, DC: Department of Defense, 2018). <https://media.defense.gov/2020/May/18/2002302061/-1/-1/1/2018-NATIONAL-DEFENSE-STRATEGY-SUMMARY.PDF>. Accessed April 9, 2025.

innovations into their operations and to change their operations considering new technologies. To ensure that an advantage in technological competition translates into improved military effectiveness, and thus strategic advantage, the United States must develop an *adaptation advantage*.

Defining Adaptation Advantage

Technological innovation generates new capabilities for military organizations. It can bring new weapons, sensors, communications, and enablers to the battlefield. All else being equal, in a competition between adversary militaries, the one with the superior technology should prevail. But all else is never equal. Between technological innovation and military effectiveness, there is a crucial step which must convert a technological advantage into a military advantage whether at the tactical, operational, or strategic level. That step is *adaptation*, the process of understanding how to employ technologies in war and developing the necessary operating concepts, force structure, and logistics necessary for employment.

New technological capabilities shape the operations of militaries in two main ways: by allowing them to carry out tasks in broadly similar, though improved, ways or by allowing for entirely new methods of accomplishing goals. Both are means by which new technologies are leveraged to improve military effectiveness—how well a military organization employs resources to achieve goals. Just how a technology will impact military effectiveness is rarely clear, and often evolves over time. Radio initially provided a better way for units to communicate over long distances, allowing for improved coordination but was later used in large-scale operational deception during the Battle of Britain and drastically changed naval nighttime combat tactics in the Pacific.

The ability of a state to better adopt new technologies into its military, and adapt its military to new technologies, is *adaptation advantage*. Holding the adaptation advantage allows states to mitigate against technological inferiority and to maximize the effects of technological superiority.

Historically, the role of technology in war has been less crucial than the role of adaptation. The Western and Eastern Roman empires had access to largely the same levels of technology, but it was the Eastern which was able to successfully adapt its forces tactically (by adopting the reflex compound bow and mounted archers) and alter its strategy to outlast the Western by nearly a millennium.⁵⁹¹ Similarly, as General Mark Milley and Eric Schmidt wrote in a recent *Foreign Affairs* article on World War II, “In the lead-up to that conflict, all advanced countries had access to the then new technologies of motorized vehicles, armored tanks, aircraft, and the radio. But the German army was a trailblazer when it came to bringing those components together.”⁵⁹² The German combined-arms blitzkrieg that punched through the French and British defenses was much more a showcase

591 For a thorough discussion on how the Byzantine Empire adopted the compound bow and altered the force structure, tactical employment, and operations of its military see Edward Luttwak, *The Grand Strategy of the Byzantine Empire* (Cambridge, MA: Harvard University Press, 2009).

592 Mark Milley and Eric Schmidt, "America Isn't Ready for the Wars of the Future," *Foreign Affairs* (September/October 2024), pp. 26-37.

of superior technological adaptation than innovation.⁵⁹³ Today, something similar can be seen in the Russia-Ukraine war, where both sides rely on technologies (e.g., drones) which they did not develop themselves and the Ukrainian advantage in adapting has allowed them to stymie Russia's advances.

Gaining and holding the adaptation advantage requires action and investment. States must spend resources to develop organizations with the skills and culture which promote desired behaviors. Behaviors like creative problem solving, technological fluency, tactical skill and operational art, and, not least, the sharing of problems and lessons learned. The cultivation of a *learning culture* within the military is critical as it allows a bottom-up dissemination of best practices and failures. The national labs also have an important role in developing the adaptation advantage: the development of technology should not happen in a vacuum but should be directed at solving important operational challenges the military faces, and the labs must develop a strong understanding of those challenges.

In this chapter, I explore historical cases of adaption advantage at tactical, operational, and strategic levels of war. Successful adaptation does not rely on a single model which functions at all times and in all places; there are significant differences in how an organization functions in peacetime, in crisis, and in conflict. Peacetime and wartime each offer different stressors and incentives for adaptation and must be evaluated for how their unique attributes impact adaptation advantages. For peacetime, I look at the role of a learning culture at work during the Interwar period as the U.S. Navy adopted and adapted to the new technologies with which WWII would be fought, most notably military aviation. For adaptation during conflict, I explore the Russia-Ukraine War and see how the battlefield has changed in the age of mass drone warfare and how new dynamics have forced changes to the military forces on both sides. Finally, I offer some recommendations on how states can employ existing tools and methods to develop adaptation advantage within their national security organizations with an emphasis on the role of the national labs.

Adaptation Before War: Amphibious Assault

*"Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after they occur."*⁵⁹⁴

– General Giulio Douhet

It is a tired cliché to say that militaries always organize and train to fight the last war over again, but this time better. While it has been true at times that military leaders relied too much on recent experience and lacked foresight, it does disservice to the amount of innovation and adaptation that has occurred between wars. Not only does it ignore successful innovations that change the nature of the next conflict, but it implies that wars are discontinuous from one another—an overstatement.

593 The failure of the French to adapt to the new speed of war is thoroughly discussed by historian, and first-hand witness, Marc Bloch in his book *Strange Defeat*. He points out several instances in which the French forces withdrew from the frontlines to regroup, but never far enough to account for the pace with which the Germans could advance. Per Bloch, "The ruling idea of the Germans in the conduct of this war was speed. We, on the other hand, did our thinking in terms of yesterday or the day before. Worse still: faced by the undisputed evidence of Germany's new tactics, we ignored, or wholly failed to understand, the quickened rhythm of the times." Marc Bloch, *Strange Defeat: A Statement of Evidence Written in 1940* (New York, NY: W. W. Norton & Company, 1999).

594 Giulio Douhet, *Command of the Air* (Tuscaloosa, AL: University of Alabama Press, 1921).

The technologies that are dominant in one war often have primordial roots in earlier conflicts. The extended fortifications and trench warfare of World War I can be glimpsed in the Battle of the Wilderness in the U.S. Civil War. Submarine warfare, which crippled the Japanese economy in World War II, began in World War I. Militaries must look back to make informed predictions about a future conflict, striving to anticipate how existing and emerging technologies will shape the next war. Lacking oracles, they are as liable to error as any organization, but often they get enough right to make a decisive difference.⁵⁹⁵

In the aftermath of World War I, the U.S. Navy found itself grappling with new strategic, operational, and tactical challenges. Strategically, a rising Imperial Japan threatened U.S. holdings and allies in Asia. Conducting naval operations in defense of areas so distant from the United States mainland and against the powerful Japanese Navy would require new operational and logistics schemes just to get forces into position. At the same time, new technologies had emerged during WWI which had to be understood and incorporated into the Navy's fighting tactics and doctrine. To meet these challenges, the Navy itself had to evolve, transforming from traditionalist organization into what historian Trent Hone has identified as a complex adaptive system.⁵⁹⁶ It developed a robust learning culture which allowed it to leverage wargaming, complex live exercises, and a safe-to-fail experimental approach to develop concepts of operations and combined arms tactics which, when tested against Imperial Japan, proved highly militarily effective.

The Pacific Ocean is vast, and ships need fuel, food, and ammunition. In a military conflict against Imperial Japan, the U.S. Navy would need to assemble, deploy, and sustain naval combat forces across a theater making up nearly one-third of the Earth's surface. For the U.S. Navy (USN) of the interwar period, and during WWII itself, maintaining enough combat force in theater to conduct an effective campaign without bases closer to the fight would have been an insurmountable challenge. The Imperial Japanese Navy (IJN) knew this and their campaign to seize islands throughout the Pacific was designed in part to deny them to the USN as resupply and sustainment points. The USN strategy, developed largely through wargaming at the Naval War College, would be to retake these islands, build up logistics and combat power, and move forward in a series of island-hopping offensives. This required the development of new operational schemes that combined air, naval, and ground forces to break Japanese defenses and seize advance bases; it was the birth of modern amphibious assault.

Amphibious warfare itself was not new; the deployment of ground troops over water has a long history, but most such operations were unopposed landings. The extensive and iterative war gaming and planning conducted by the USN during the Interwar Period established a need for forces capable of fighting and defeating an entrenched adversary at contested landing sites. The Pacific Islands which could provide suitable bases were small enough for Japanese garrisons to defend viable landing sites and often close enough to other occupied islands to provide air support. Every island converted into a forward USN base would have to be taken by assault, and that would require developing new forces, capabilities, and tactics.

595 For an account of the many failures, and few successes, of war oracles, see Lawrence Freedman, *The Future of War: A History* (New York, NY: PublicAffairs, 2017).

596 Trent Hone, *Learning War: The Evolution of Fighting Doctrine in the U.S. Navy, 1898-1945* (Annapolis, MD: Naval Institute Press, 2018).

The Marine Corps embraced the requirement, taking ownership of the mission and working with the Navy to equip and adapt their force to the challenge. Officers at the Marine Corps School and Naval War College devoted increasing amounts of time and intellectual energy to the development of amphibious assault doctrine and the services invested resources into a series of increasingly complex Fleet Landing Exercises (FLEXes).⁵⁹⁷ The FLEX exercises allowed Marine and Naval forces to test out the theories of amphibious assault in environments that came as close to real-world combat as possible. Under these conditions, with real marines and sailors using actual equipment, some of the friction inherent to war could be introduced, exposing failure points that would go unnoticed in theoretical work. Arguably, the failure of equipment, tactics, and theory provided more benefit than would come from the successful validation of any given concept of operation. As explained by Marine General Charles Krulak:

The after-action report called the exercise a “fiasco.” ... Many of the Marines’ critics said, “I told you so.” Again, the Marines saw it differently. In one observer’s opinion, the fiasco at Culebra in 1924 identified enough errors to keep the Corps busy for 15 years. The experiment in 1924, and the subsequent experiments in the years leading up to World War II, allowed the Corps to forge ahead in tactics, and equipment that later proved decisive in not only the Pacific but the European and North African theaters as well.⁵⁹⁸

Building the connection between exercises, experimentation, and equipment development lies at the heart of adaptation advantage. A healthy organization embraces success and failure and translates both into capability. The Navy and Marine Corps did exactly this in developing their amphibious assault forces. From their work, they distilled several core tenets of amphibious assault: Close integration of air and naval gunfire to suppress enemy defenses, a wide-front and violent assault over the beach, the need to rapidly reinforce beachheads with armor and artillery, and prolonged defense against enemy air and naval counterattacks.⁵⁹⁹

Each tenet gave rise to their own set of tactical and technical requirements which often required new technological solutions—whether through new development or adaptation of existing systems. Shallow-draft landing vehicles were to move men and materiel ashore, leading to the development of Higgins boats and adapted from boats originally designed to navigate the bayous of Gulf-front Louisiana. The Marines also recognized that artillery designed for mountain warfare shared tactical requirements with those needed for amphibious assault artillery—that is, a requirement for lightweight and rapid setup and breakdown.⁶⁰⁰ Not everything required a bespoke solution and with

597 Alan Millet, "Assault from the Sea: The Development of Amphibious Warfare between the Wars—the American, British, and Japanese experiences," in *Military Innovation in the Interwar Period*, Williamson Murray and Alan Millet, eds. (Cambridge, UK: Cambridge University Press, 1996), pp. 50-95.

598 Charles Krulak, "Innovation, the Warfighting Laboratory, Sea Dragon, and the Fleet Marine," *Marine Corps Gazette* (December 1996), p. 13.

599 Alan Millet, "Assault from the Sea: The Development of Amphibious Warfare between the Wars—the American, British, and Japanese experiences."

600 Ibid.

limited budgets, identifying commonality of requirements allowed for more efficient acquisition of capabilities.

The development of amphibious assault capabilities by the United States Marine Corps (USMC) and USN before the outbreak of World War II shows adaptation as a process where requirements flow down and solutions flow up. The United States benefited from having an identified adversary around which to shape their strategy. High-level and rigorous war gaming allowed the USN to plan wartime campaigns and identify operational requirements and gaps. A Marine Corps willing to take ownership of a crucial aspect of the strategy was able to experiment and exercise existing systems and doctrine and find out what created success and what created failure. New, or adapted, systems were then fielded along with new tactics in an iterative cycle to patch gaps and repair failure points. Iteration was crucial, as was getting equipment and tactics into the field with real marines, sailors, and soldiers using them under real-world conditions. They developed a force equipped with the right materiel solutions and an effective combined arms doctrine that, in the final test of actual warfighting, was able to meet its operational requirements of advance base seizure and defense that enabled the U.S. victory in the Pacific. In contrast, the Japanese developed their own significant amphibious landing capabilities but in testing them against the much weaker Chinese forces and on lightly or undefended islands, failed to develop the full suite of assault capabilities and doctrine. The telling point showing American strategic advantage is that the Japanese never retook any island seized by U.S. amphibious assault.

Adaptation During War: Russia-Ukraine War

“There is no better teacher of war than war.”⁶⁰¹

– Mao Tse-Tung

Regardless of how well organizations perform at adapting themselves to an anticipated conflict, war itself is the ultimate arbiter of military effectiveness. Operational schemes and plans which showed promise in pre-conflict wargames, simulations, or even live exercises may show themselves to be impractical or ineffective against the adversary. The assessment of the adversary’s capabilities, intentions, and strategies may prove to be woefully inadequate, leaving our forces ill-prepared or out of position to prevent early tactical or operational-level success. But, provided sufficient resilience and capability to prevent a total strategic defeat, there is opportunity to adapt to the situation and respond. England faced this kind of situation at the beginning of World War II and was able to stabilize the situation and adapt its warfighting approach. An effective military organization uses what it learns during peacetime and competition as a basis for further adaptation during conflict, tossing out failed concepts and refining successful ones, disseminating lessons learned, and continuously re-appraising its tactical, operational, and strategic effectiveness.

Today Ukraine has staved off the initial rapid but poorly executed Russian assaults, stabilized the front lines, and inflicted high costs on the Russian invasion forces. Ukraine’s ability to hold out against its much larger and stronger neighbor is fueled, in large part, by resources provided by the United States and European allies, but Ukraine has proven skillful in the use of those resources to

601 Mao Tse-tung, *On the Study of War* (1936).

achieve military and political objectives. Though still outgunned, outmanned, and with a smaller economic and industrial base to draw upon, Ukraine has demonstrated a high capacity for adapting. It has rapidly integrated non-indigenous technologies into its military, both in the form of Western-provided military systems and weaponized commercial drone technologies. Further, it has instituted organizational changes to its armed forces, pulling away from their Soviet roots to be more aligned with the North Atlantic Treaty Organization (NATO). In several key aspects—though not all—Ukraine has established an adaptation advantage over Russia. Whether those advantages will be sufficient to overcome the Russian military has yet to be determined.

Drone warfare has proven to be a central element in Ukraine’s defense against Russia, with unmanned systems deployed in huge numbers by both sides. The advancement in drone technology, along with the relatively low cost of production, has ushered in what Michael Horowitz has described as the “age of precise mass.”⁶⁰² Ukraine has proven highly skillful in adapting to the new era. The use of armed drones is not new to this conflict, as the United States has been employing drones like the Predator and Reaper for long-duration aerial surveillance and precision strike missions for nearly three decades. More recently, the Second Nagorno-Karabakh War saw the use of drones and loitering munitions against armor. The scale of drone use in the Ukraine-Russia conflict is significantly greater though, with thousands of unmanned systems deployed on both sides and Ukraine’s industry restructured to produce four million drones annually.⁶⁰³

Ukraine’s adaptation of—and to—drone warfare has been thorough, creating changes in how it conducts war at the tactical, operational, and strategic level. It has employed small, relatively cheap aerial drones for surveillance and targeting, as well as for precision deep strike. Using drones, Ukrainian defenders can maintain high levels of battlefield awareness to find enemy forces and conduct attacks—either calling in artillery fire, missile strikes, or using the drones themselves—in as little as a minute.⁶⁰⁴ Success in war is most often the result of achieving a favorable attrition rate over the adversary.⁶⁰⁵ According to the Institute for the Study of War, “Ukrainian innovation has already enabled Ukraine to manage this attrition gradient through reducing costs and inflicting asymmetric losses on Russian forces.”⁶⁰⁶ Ukrainian forces employ various types of drones to direct artillery fire, to precisely strike armored units (which has led to counteradaptation such as anti-

602 Michael Horowitz, “Battles of Precise Mass: Technology is Remaking War and America Must Adapt,” *Foreign Affairs* (November/December 2024), pp. 34-41.

603 Olena Harmash, “Ukraine Ramps Up Arms Production, Can Produce 4 Million Drones a Year, Zelenskiy says,” Reuters (October 2, 2024). <https://www.reuters.com/world/europe/ukraine-ramps-up-arms-production-can-produce-4-million-drones-year-zelenskiy-2024-10-02/>. Accessed December 26, 2024.

604 Mick Ryan, *The War for Ukraine: Strategy and Adaptation Under Fire* (Annapolis, MD: Naval Institute Press, 2024).

605 For a thorough exploration of the role of attrition versus decisive battle in war termination, see Cathal Nolan, *The Allure of Battle* (New York, NY: Oxford University Press, 2017).

606 Riley Bailey and Frederick Kagan, “A Defense of Taiwan with Ukrainian Characteristics: Lessons from the War in Ukraine for the Western Pacific,” Institute for the Study of War (October 30, 2024). <https://www.understandingwar.org/backgroundunder/defense-taiwan-ukrainian-characteristics-lessons-war-ukraine-western-pacific>. Accessed December 26, 2024.

drone “cope cages”⁶⁰⁷), and to supplement artillery support (in which Ukraine has a persistent quantitative disadvantage) through direct drone attack. Beyond the tactical level, Ukraine has instituted organizational changes, forming special drone attack companies that could carry out full end-to-end missions themselves rather than having forces dispersed among more traditional combat units.⁶⁰⁸ This has created an operational-level capability for coordinating long-range and massed deep strikes designed to disrupt Russian logistics and corrode its combat power. A particularly noteworthy achievement has been Ukraine’s ability to deny large areas of the Black Sea to the Russian Navy despite not having its own navy.⁶⁰⁹ And, as noted above, Ukraine has restructured its defense industry to meet the growing demand for drones to achieve and maintain a strategic advantage over Russia in this aspect of the war.

In this war, the Ukrainian and Russian militaries have both adapted their ways of war at the tactical, operational, and strategic levels with varying levels of success and in different ways. The contrast in those adaptations is stark, considering the organizations’ shared history. Both nations are former Soviet states, with strong commonalities in their military doctrine, organization, and learning culture; further, both nations are adopters rather than progenitors of drone technology. The divergence in their ability to operationalize drone warfare is therefore much more about adaptation than technological innovation. One factor in Ukraine’s favor is an asymmetry of incentives. Ukraine, at a disadvantage in terms of manpower and materiel and with its statehood existentially threatened, had much greater need to adapt low-cost solutions which could tilt the attrition balance in its favor. Russia has relied on simpler tactical adaptations such as human wave “meat assaults” which relied on its own existent advantages of manpower and materiel rather than technological solutions. There is a danger in viewing the Ukrainian approach as superior over the Russian, but that is not guaranteed as Russia still holds a significant advantage in war resources and Ukraine is limited by the amount of Western military assistance provided. The Ukrainian military has seemingly achieved a measure of adaptation advantage in drone warfare; the hope is that this will translate into a war-winning strategic advantage, but the final arbiter of that question will be the war’s conclusion.

Ukraine’s adaptation advantage did not emerge *ex nihilo* in February 2022 as Russia launched its invasion. It is an organizational capability which Ukraine’s armed forces have invested in developing over time, making crucial decisions to turn away from their Soviet legacy. In *The War for Ukraine: Strategy and Adaptation Under Fire*, retired Australian Major General Mick Ryan identifies the key elements of Ukraine’s organizational adaptation advantage.⁶¹⁰ The 2014 Russian invasion and seizure of Crimea provided both a major impetus for military reform and a lesson on modern Russian

607 The development of field solutions by survival-motivated soldiers is not unique to Russia, and the inelegancy of the “cope cages” does not diminish their efficacy. The U.S. forces serving in Iraq faced similar adaptation pressures from roadside improvised explosive devices (IEDs) and convoy attacks. Nina Kollars’ study of gun truck development during Operation Iraqi Freedom covers this dynamic and highlights a similarly low-tech, in-field adaptation known as “hillbilly armor.” Nina Kollars, “Military Innovation’s Dialectic: Gun Trucks and Rapid Acquisition,” *Security Studies* (2014), pp. 787-813.

608 Mick Ryan, *The War for Ukraine: Strategy and Adaptation Under Fire*.

609 Riley Bailey and Frederick Kagan, “A Defense of Taiwan with Ukrainian Characteristics: Lessons from the War in Ukraine for the Western Pacific.”

610 Ryan’s book draws on the cultural innovation studies of Williamson Murray, Barry Watts, and Peter Mansoor along with a thorough open-source study of the Russia-Ukraine conflict to synthesize the adaptation competition in Ukraine. Mick Ryan, *The War for Ukraine: Strategy and Adaptation Under Fire* (Annapolis, MD: Naval Institute Press, 2024).

military capabilities and doctrine. Ukraine undertook major changes in its armed forces designed to pull it away from its Soviet roots and toward a more NATO-like force. This has included an emphasis on communication up and down the chain of command, with increased authority and reliance on mid-level officers and operators at the tactical level. Unlike the Soviet model of highly centralized command, this encourages adaptation by allowing more solutions to bubble up from those closest to the fight along with more honest and full appraisals of operational challenges. The focus on Russia as an adversary also allowed Ukraine to develop tailored strategies and prepare not just its military, but its society at large for what would be expected of them in wartime. The post-2014 reforms continued, and in many ways accelerated, though the 2022 invasion have enabled Ukraine's adaptation under fire, creating the organizational skills and capacities to bring in new Western systems, adopt low-cost off-the-shelf drone systems, and slant the attrition ratio in its favor.

Building Adaptation Advantage: Tools and the Role of the Lab

"[T]he most important competition is not the technological competition, although one would clearly want to have superior technology if one can have it. The most important goal is to be the first, to be the best in the intellectual task of finding the most appropriate innovations in concepts of operation and making organizational changes to fully exploit the technologies already available and those that will be available..."⁶¹¹

– Andrew Marshall

One reason the British failed to develop long-range fighters prior to World War II, according to Williamson Murray's analysis, was a lack of technical engineering knowledge among British airmen.⁶¹² The military officers were convinced that such craft was infeasible if not impossible to develop—until the American P-51 showed up. Successful military adaptation of, and to, new technological capabilities rely on open, two-way communication between the military and technology developers. Tactics developed without an understanding of technical limitations will prove either unworkable or will underutilize the new systems. In the opposite direction, technologies developed without a clear sense of military operational realities and objectives will struggle to find adopters. In order to be successful in converting scientific progress into military effectiveness and creating a U.S. adaptation advantage, the national labs must understand the challenges and capability gaps of the military organizations—and fit technological solutions into relevant, credible military situations. They must also educate military organizations on the capabilities and limitations of new technologies. Under- and overselling are equally dangerous. Developing the two-way conversation of military and technological context requires the Lab to leverage core capabilities such as high-performance computing in new ways and build stronger ties to operational warfighting communities.

611 Andrew Marshall, "Some Thoughts on Military Revolutions - Second Version" (Washington, DC: Office of Net Assessment, U.S. Department of Defense, 1993). <https://stacks.stanford.edu/file/druid:yx275qm3713/yx275qm3713.pdf>. Accessed April 9, 2025.

612 Williamson Murray, "Armored Warfare: The British, French, and German experiences," in *Military Innovation in the Interwar Period*, Williamson Murray and Alan Millet, eds. (Cambridge, UK: Cambridge University Press, 1996), pp. 6-49.

Find the Problem. The national labs should be in the business of using technology to solve our national security challenges. This is inherently different from taking a particular technology in search of a problem. Communication between the military and the labs is crucial, and it ideally starts with the military talking and the labs listening. The military services and combatant commands have wide responsibilities to develop, equip, and employ military resources and personnel in pursuit of our national security goals. There are always challenges, capability and capacity gaps, in fulfilling those obligations—holes in the theory of victory. Engaging at the combatant command level ensures that the problems identified are grounded in a realistic context with actual expected missions against expected adversaries. America’s successful development of amphibious assault was shaped largely to meet the specific operational challenges posed by Imperial Japan, not some generic and theoretical adversary. Some of the challenges may be addressable by appropriately adapting existing or emerging technologies but that adaption is only possible when challenges are known and defined. The labs should work to develop an in-house knowledge base of military experts by recruiting recently separated/retired military personnel (tactical proficiency is an extremely perishable skill and begins to decay immediately) to inform its efforts. They should also focus on developing direct links with combatant commands, the organizations most likely to understand the current capability and capacity gaps challenging their ability to achieve national security goals. Other organizations worth developing connections with include the various warfare development centers. As trusted partners, the national labs and the military can more freely share an understanding of the challenges and opportunities that can be met through technological adaption.

Embrace Failure. Developing a strategic advantage in adaptation will not mean the United States will successfully transition all new technologies into effective military capabilities. It certainly will not mean that we will get everything correct when we predict how a new technology could or should elicit changes in military operations. Failure must be not just tolerated but planned for. Trent Hone’s analysis of the U.S. Navy during the Interwar Period identified failure tolerance and parallel experimentation as a key enabler of the organization’s learning and adaptation culture.⁶¹³ Experimenting with bottom-up solutions allows sub-elements of an organization to try new systems and procedures to find options best suited for their specific needs and context. Experimenting at lower levels of the organization (on individual ships or squadrons) opens the aperture for finding solutions and identifying technical limitations and opportunities. This requires more time and acceptance of more failures across the organization but will lead to a better understanding of capabilities and better fit solutions. In contrast, requiring global “one size fits all” solutions can force an organization to prematurely select systems for adoption across its sub-elements with potentially widely diverse capabilities and mission requirements.⁶¹⁴ There will never be perfect oracles for transforming technological advancement into military capability; multiple avenues need to be explored and the military and the technology developers must be prepared for and accept that many

613 Trent Hone, *Learning War: The Evolution of Fighting Doctrine in the U.S Navy, 1898-1945* (Annapolis, MD: Naval Institute Press, 2018).

614 This "race to the bottom" dynamic to explore in the context of naval unmanned systems by LCDR Justice and myself in a 2019 CIMSEC article: Daniel Justice and Dustin League, "Create an Unmanned Experimental Squadron and Learning System," Center for International Maritime Security (May 6, 2019). <https://cimsec.org/create-an-unmanned-experimental-squadron-and-learning-system/>. Accessed December 26, 2024.

of those avenues will be failures. They need to plan for those failures with a learning culture ready to exploit lessons learned from failure as well as success.

Play Games. Lots of Games. Part of creating a safe-to-fail organization is establishing environments with lower stakes. Operations research, in particular modeling and simulation, offers techniques for experimentation with military concepts and systems without risking equipment or human losses. These range from tabletop human-driven games to complex computer models able to simulate thousands of interacting entities over various times and geographic scales. While they will never be able to capture the full friction of war, they can provide an environment perfect for rapidly testing out new concepts of operation and new systems. One of the best uses of these capabilities is winnowing a handful of promising solutions from a mountain of ineffectual chaff. Games also facilitate defining clear measures of effectiveness, which allow for clear, level comparison of alternatives.

Marrying the high-performance computing capabilities of the national labs with conflict modeling software should allow for testing a wide range of concepts and generating prompt understanding of what works, what fails, and why across a variety of military situations. Machine learning and other forms of artificial intelligence can also play a role here, allowing for more dynamic and unscripted interactions between simulated entities and a wider scope of tactics employed. Repeated gameplay is also important to separate failed capabilities from poor gameplay—a single game of chess is not enough for any player to grasp the intricacies of the base game, let alone understand how to adapt new capabilities into advantageous strategies. The combination of increasingly detailed conflict modeling with machine-directed entities able to run thousands of simulations may even enable discovery of emergent, effective tactics and strategies.

Live Fire. Humans have a tremendous facility for breaking things—soldiers, sailors, and marines even more so. This is true for tactics and concepts of operation as much as it is for equipment. The knowledge that they may be trusting their lives to a new capability gives them strong motivation for finding its limits. This can not only expose limitations of a system or concept, but also identify new ways a system can be employed beyond its intended design. This is where the rubber of technological innovations meets the road of military adaptation. It will be human operators who eventually employ every piece of technology; they are the ones who will or won't adopt systems and adapt themselves to their use. Getting equipment into their hands early so they can use it, test it, experiment with it, and break it is crucial. This must happen in peacetime but also, as seen with the Ukrainian adaptations to drone warfare, during conflict. Rapid prototyping and distribution to potential end-users, with plans for documenting and disseminating lessons learned, is crucial to adaptation. The national laboratories need to expand their ability to develop prototype systems and draft concepts of employment, get equipment into the hands of its intended users, coordinate realistic testing with the military services, and digest results of live, in-the-field exercises.

One Nation. Adaptation as a national strategic advantage requires national-level coordination. The Services and the national labs play important roles, but their efforts must be synthesized into a cohesive strategy to fight against parochial interests. Future operating concepts and technologies should be expected to disrupt the established mission sets, potentially removing core missions from one Service and giving it to another. Competition is healthy but requires a fair arbiter and a level assessment field. Developing a common set of scenarios driven by, and responsive to,

national strategy with clear metrics of success would go a long way toward establishing that healthy competition.

The armed forces should not be alone in bringing new concepts to the table either; the United States has economic, diplomatic, cultural, and informational power that must also be employed, and the organizations employing that power must also cultivate adaptive capabilities. Our adversaries have had ample opportunity to see how we employ non-military power such as sanctions. They have learned to adapt, reducing reliance on Western technology and trade, and finding willing partners in other nations we have attempted to isolate. The United States must study all the ways and means available for meeting national objectives, understand how our adversaries are defeating or intend to defeat our traditional approaches, and develop new concepts and new capabilities across all elements of national power.

Conclusion

Creation of advanced technologies is no guarantee that such achievements will provide a nation with a strategic advantage. Technology must be harnessed and operationalized in service to specific goals. The United States has a rich history of successful adaptation of technology to military ends, and of military ways to new technology, but that adaptation advantage is also not guaranteed. Many military-relevant technologies being developed today will be as available to competitor and adversary states as soon, or nearly as soon, as they are to us. The Russia-Ukraine war has shown how rapidly second adopters, or close followers, of a technology are able to operationalize technology in service of war. Other emerging technologies are likely to follow similar trends, especially between peer and near-peer states. The United States must prepare to achieve strategic advantage in a world where technological superiority in any given field is, at best, fleeting.

Such a situation should be seen as the norm, with the technological overmatch enjoyed by the United States during the wars in Iraq and Afghanistan as the aberration. Most of history has seen wars fought between combatants with broadly similar levels of technology. Even the post-Industrial Era World Wars were more competitions in *application* than *development* of technology. Nazi Germany developed a more effective concept of armored warfare than the French and British not because they had better technology, but in spite of treaty restrictions that severely limited their access to the core components. Imperial Japan developed the technologically superior “Long Lance” torpedo for their submarines yet failed to significantly hamper U.S. shipping in the Pacific even as the less well-armed U.S. submarines eviscerated Japanese commerce.⁶¹⁵ Better understanding of technologies’ capabilities and limitations, and more thorough and honest appraisal of conflicts (past and present) allow military organizations to develop stronger concepts of operation. In war, the fitter concepts survive and the flawed are discarded. This too is fluid, as any healthy military learns from success and defeat, creating an action-reaction cycle. The German blitzkrieg was successful against France but overran its own limited logistics capacity against Russia and was defeated. The Ukrainian and Russian militaries are, as of this writing, locked in an action-reaction cycle on an evolving battlefield with no clear indication

615 Williamson Murray, "Innovation: Past and Future," in *Military Innovation in the Interwar Period*, Williamson Murray and Alan Millet, eds. (New York, NY: Cambridge University Press, 1996), pp. 300-328.

of which side will ultimately prevail. Adaptation advantage means building better ideas, not better equipment.

Strategic advantage is never about a single element of a nation's power. This chapter has focused on militaries' adaptation to new technologies, but adaptation advantage is not solely a military requirement. The developers of new technologies need to cultivate an understanding of operational realities—military and otherwise—to focus effort and prioritize investment. This requires developing conflict modeling and simulation capabilities that leverage the national labs' core capabilities in new ways. It requires fielding test systems in realistic environments for safe-to-fail and stressful experimentation. More than anything, it requires direct, open, and robust bi-directional communication between technology developers and end users. Without such connections, the technologists risk creating solutions in search of problems while the operators fail to understand the full range of capabilities that may be available. These are organizational traits not reliant on individual geniuses; they require investment and commitment, but they pay off for decades. Combining technological innovation with effective learning and adaptation capabilities will create an enduring advantage for the United States.

Wargaming Technology Competition: Evaluating Wargaming as a Methodology

Ross Buchanan

Introduction

While discussions of technology competition tend to focus on the development of technological instruments, an equally important and often underappreciated aspect of technology competition is understanding the methods for using such instruments. The effectiveness of any tool depends on how it is wielded, and innovative methods for using existing tools can grant new capabilities. For this reason, understanding and predicting how technologies will be used in future conflicts can grant important strategic advantages. Such insights may help a country (or other actor) to improve its strategies for using existing or speculative technologies, anticipate adversaries' strategies, and predict how competing actors may adapt and counter-adapt to one another.⁶¹⁶

This chapter assesses the usefulness of wargaming as a methodology for predicting innovations in how instruments are used.⁶¹⁷ To this end, I examine an emerging technology that has had a transformative effect on the ongoing conflict in Ukraine: aerial drones. My analysis looks at three pre-2022 wargames that made predictions about near-future conflict and evaluates how well they predicted the innovative use of drones in the Russo-Ukrainian war since February 2022, as well as how well they identified the implications of those innovations for the conflict.⁶¹⁸ The goal of this analysis is three-fold. First, determine what wargames can—and cannot—tell us about technology competition. Second, identify key characteristics of wargames that have made correct predictions. Third, outline ways in which future wargames can improve. My central argument is that wargames can predict future strategies for using emerging technology if they meet several conditions: 1) they explicitly incorporate a technology of interest as a tool players can use, 2) they clearly specify the technology's capabilities in their rulesets or scenario descriptions presented to the players, 3) the capabilities specified by the game reflect reality, and 4) the game design does not engineer a particular outcome.

This chapter is organized as follows. I define the key concepts of *technology*, *technology competition*, and *wargaming* in Section 2. I explain that wargames have advantages as well as

616 Wargames can also be used to evaluate what perspective technical capabilities are most useful for achieving a given set of goals. In this way, they can inform investment decisions when developing new capabilities.

617 Wargaming is an increasingly popular approach employed by those attempting to anticipate future competitive dynamics in the military and commercial domains. The methodology's success, however, has so far not been well explored. See Clayton Schuety and Lucas Will, "An Air Force 'Way of Swarm': Using Wargaming and Artificial Intelligence to Train Drones," *War on the Rocks* (September 21, 2018), <https://warontherocks.com/2018/09/an-air-force-way-of-swarm-using-wargaming-and-artificial-intelligence-to-train-drones/> (accessed March 28, 2025); Jan Oliver Schwarz, Camelia Ram, and René Rohrbeck, "Combining Scenario Planning and Business Wargaming to Better Anticipate Future Competitive Dynamics," *Futures* 105 (January 2019), pp. 133–42, <https://doi.org/10.1016/j.futures.2018.10.001>.

618 I selected these three pre-2022 wargames based on three criteria: 1) their relevance to this chapter's topic, 2) their degree of transparency regarding their methodology and findings, and 3) the degree to which they provide a diverse range of wargaming formats for this chapter. I cite and briefly describe two notable drone-related wargames that I did not use in my analysis in the final section of this chapter.

inherent limitations. The methodology can predict how a technology with a given set of capabilities will be used in future conflicts. It can also offer insights into the implications of such a technology being used in innovative ways. However, wargames cannot predict a technology's technical capabilities.⁶¹⁹

In Section 3, I provide a brief overview of how drones have been used in Ukraine since February 2022 and how drone use has transformed the conflict. This section provides the baseline against which the predictions of the wargames examined in the following section are compared. It shows that the Ukraine conflict has seen a revolution in the methods for using drone technologies that predated the war. It also identifies several important ways in which drone use has affected how the conflict has played out since early 2022.

Section 4 examines three pre-2022 wargames and compares their predictions about future conflict to what we have seen in Ukraine so far. The wargames are the Center for a New American Security's (CNAS) 2015 Game of Drones, a 2020 United States Air Force (USAF) wargame, and RAND's 2014-2015 Baltic Defense Wargame. These games represent three distinct approaches to accounting for emerging technology when making predictions about how future conflicts will be fought. The CNAS wargame was a relatively low fidelity, loosely structured game that examined drones across a dozen separate mini scenarios. The USAF wargame was a high fidelity, highly structured game that examined drones in a single scenario. The RAND wargame was highly structured, examined a single scenario, and fell somewhere between the CNAS and USAF wargames in terms of fidelity. In this section, I find that the CNAS and USAF wargames' predictions have held up remarkably well since 2022 while the RAND wargame's predictions have not. This result is especially remarkable given that the RAND wargame's scenario resembled the opening of the Ukraine conflict much more closely than did the scenarios in the CNAS and USAF games.⁶²⁰

Section 5 explains how the three wargames demonstrate the strengths and weaknesses of wargaming as a methodology. This section builds on the discussion of the methodology's theoretical strengths and weaknesses in Section 2. It also argues that the three wargames show how well-designed games can offer insights that apply beyond their specific scenarios. In Section 6, I compare the three wargames' designs and synthesize a list of the essential features for wargames that examine technology competition. My overarching argument in this section is that the CNAS and USAF wargames made mostly correct predictions because they explicitly incorporated their emerging technology of interest (drones) as tools for the players to use while the RAND wargame did not.⁶²¹ I conclude in Section 7 by outlining a path forward for improving wargaming as a methodology for studying technology competition.

619 For instance, wargames cannot predict the performance of prospective jet engines or quantum computers' designs.

620 The RAND scenario depicted the start of a Russian invasion of an Eastern European neighbor in which Russia was attempting to rapidly occupy the adversary's capitol and dissuade intervention by North Atlantic Treaty Organization (NATO) members. The scenarios used by the other games were not even set in Eastern Europe, nor did they include Russia as a player.

621 The RAND wargame did not explicitly incorporate drones (or any other emerging technologies) into its design. Instead, it made implicit assumptions about how drones would be used in a future conflict and built these assumptions into the combat effectiveness values it assigned to the combat units represented in the game.

Key Concepts

Technology

Technology is any capability given by the practical application of knowledge.⁶²² This definition encompasses both instruments and methods for using instruments to grant capabilities. Technologies like bronze and steel, swords and shields, steam engines and textile looms, computers and software are all instruments that grant capabilities.⁶²³ Technology also includes methods for using instruments to grant new or enhanced capabilities. Assembly line methods for mass production are technologies that leveraged instruments like steam engines and electricity to improve the efficiency and scale of production.⁶²⁴ In the military domain, technology encompasses tactics and strategies, which are methods for using instruments to achieve military ends. *Levée en masse* (mass conscription) was a technology developed by revolutionary France in the 1790s to bolster its defenses against its hostile neighbors. It leveraged advances in firearms to make conscripted soldiers with limited training combat effective.⁶²⁵ As another example, *blitzkrieg* was a mid-20th century technology developed by Germany that leveraged aircraft and tanks (instruments that had emerged two decades earlier in World War I) to rapidly conquer most of Europe.

Technology competition

Technology competition refers to competing efforts by two or more actors to develop new or improved instruments and methods that grant capabilities. Technological competition is important in the national security context because it is fundamental for most other forms of competition between countries, particularly in the military and economic domains. In the military domain, a force with more advanced technology tends to have an advantage over a force with less advanced technology.⁶²⁶ Technology is similarly essential for a country's economic capacity. Along with population and resource constraints, technology is a key determinant of economic output.⁶²⁷ Technology is also a critical determinant of the quality of goods and services a society produces, which has a strong impact on a nation's welfare.

622 "Technology," in *Merriam-Webster.Com Dictionary* (November 23, 2024). <https://www.merriam-webster.com/dictionary/technology>. Accessed March 28, 2025.

623 More recent examples of technology include hypersonic missiles, quantum computing, and machine learning algorithms.

624 Bryan H. Bunch and Alexander Hellemans, *The History of Science and Technology: A Browser's Guide to the Great Discoveries, Inventions, and the People Who Made Them, from the Dawn of Time to Today* (Boston: Houghton Mifflin, 2004).

625 A decade later, the technology helped Napoleon Bonaparte conquer most of Europe.

626 As an example, a fighter aircraft with guided missiles tends to have an advantage over a similar aircraft armed only with guns. However, this is not to say that more advanced technologies *always* perform as well as expected or outperform less advanced technologies. For instance, the U.S. Air Force transitioned from using guns in their aircraft to using only missiles shortly after World War II. However, the U.S.'s Sparrow air-to-air missile underperformed in the Vietnam War so dramatically that the United States re-equipped its fighter aircraft with guns (as well as a loadout of missiles). See Marshall L. Michel, *Clashes: Air Combat over North Vietnam, 1965-1972*, 1. printing (Annapolis, Md: Naval Institute Press, 1997).

627 Technology is also important for economic competition below the aggregate national level. Companies with better technology will tend to outcompete companies with inferior technology internationally and domestically.

Wargames

A wargame is a representation “of conflict in which the game’s players make decisions and respond to the consequences of those decisions.”⁶²⁸ As such, wargames have three defining characteristics: 1) they require players to make decisions in response to a situation, 2) they present players with the outcomes of those decisions, and 3) they require players to make subsequent decisions that deal with the outcomes of their earlier choices. Decisions are fundamental to wargames, as all wargames consist of a series of player decisions.

At their core, wargames are a type of survey. When players make moves in a wargame, they are essentially filling out a survey created by the wargame designer that asks how the respondent thinks they should address a given situation.⁶²⁹ The distinction between wargames and other survey types is that wargames present players with the outcomes of their decisions and ask them to respond to those outcomes. By forcing players to respond to a dynamic environment in which their decisions have consequences, wargames have the potential to produce insights that would not be possible with alternative methodologies like standard expert surveys.

Wargames are well suited for studying methods for using technologies with specified capabilities.⁶³⁰ They can examine how competing players leverage technologies with defined capabilities to gain an advantage over one or more adversaries. They can therefore identify innovative strategies for using particular technologies and offer predictions about how competing players may adapt to such innovations. Gaining these insights grants at least three major advantages to an actor and its ability to compete against adversaries. First, they facilitate the development of better strategies. Second, they allow one to anticipate an adversary’s methods and develop effective countermeasures. Third, they allow one to assess the practical usefulness of emerging technologies, which can inform investments into the research and development of such technologies.

Wargames do not assess the technical performance of technologies, and they are not appropriate for predicting how technical performance will evolve. The capabilities assigned to technologies in a wargame are assumptions built into the game’s design. These assumptions are made by the wargame’s designers to align with their research goals. Wargames intended to examine existing technologies make grounded assumptions about technical capabilities, often based on real-world experience. Wargames intended to examine possible uses of prospective technologies make assumptions about speculative technical capabilities that may be available in the future. Playing a wargame shows the decisions players make under the game’s assumption, but it does not determine

628 “Defense Analysis: Additional Actions Could Enhance DOD’s Wargaming Efforts” (Government Accountability Office, April 2023), 1, <https://www.gao.gov/assets/gao-23-105351.pdf> (accessed March 28, 2025); see also Peter P. Perla, *The Art of Wargaming: A Guide for Professionals and Hobbyists* (Annapolis, Md: Naval Institute Press, 1990); Jeff Appleget, Robert Burks, and Fred Cameron, *The Craft of Wargaming: A Detailed Planning Guide for Defense Planners and Analysts* (Annapolis, Maryland: Naval Institute Press, 2020).

629 Just as in conventional surveys, there are many formats for questions in wargames. Questions can be open-ended or closed-ended, oral or written, simple or complex. Questions may also ask for non-verbal responses, such as asking respondents to move items on a map.

630 Wargames can also be used as educational tools. Educational wargames are designed to impart useful information to the players. The information it imparts to the players may be general and experiential (e.g., demonstrating to players that interpersonal communication can break down in stressful situations) or highly specific and technical (e.g., educating a pilot about how to engage enemy aircraft). Wargames are usually designed to be either educational or analytical, but there is no technical reason that a given wargame could not be used to fulfill both purposes.

whether the assumptions are correct. In general, the validity of a wargame’s findings regarding technology are contingent on the validity of the wargame’s assumptions about technological capabilities.

The Russo-Ukrainian War’s Drone Revolution

Drones have been used extensively by both Ukraine and Russia since February 2022. Most of the drones are relatively small, often weighing a few tens of kilograms or less. Many of these are repurposed commercially available models that were not originally designed for combat. Larger drones such as the Bayraktar TB2 and the Shahed-136 have also seen widespread use. There were steady advancements in drone capabilities in the years leading up to 2022, and the outbreak of full-scale war in Ukraine has likely accelerated the pace of advancement. The methods for using drones have become quite sophisticated. Drones have been used independently and in combined arms operations, and there is significant differentiation in how large and small drones of different designs are used. Large drones tend to be used for long range and high endurance missions while small drones are used for tactical operations.⁶³¹ Drones of all sizes have been used to fulfill a wide range of roles, including carrying out kinetic strikes, acting as decoys, and conducting intelligence, surveillance, and reconnaissance (ISR) operations.⁶³²

The technology revolution⁶³³ we have seen in Ukraine has been in the methods for using drone capabilities that predate the conflict. Militaries have used drones as guided munitions, decoys, and reconnaissance platforms, since at least the 1960s.⁶³⁴ However, drones have historically been niche assets that have been highly specialized, expensive, and used only in small numbers.⁶³⁵ In Ukraine, drones have been used more extensively across a far wider range of roles than in any previous conflict. The extensive use of drones has been made possible by leveraging low-cost/low-capability drones, which can be deployed in greater numbers and exposed to more attrition than other military assets with comparable capabilities. The Ukrainians were the first to begin leveraging low-cost drones at scale—an innovation that was driven by desperation as they were otherwise badly outmatched by Russian forces. Russia quickly followed suit by employing their own drones at scale.⁶³⁶

631 Dominika Kunertova, “The War in Ukraine Shows the Game-Changing Effect of Drones Depends on the Game,” *Bulletin of the Atomic Scientists* 79, no. 2 (March 4, 2023), pp. 95–102. <https://doi.org/10.1080/00963402.2023.2178180>. Accessed March 28, 2025.

632 Margarita Konaev, “Tomorrow’s Technology in Today’s War: The Use of AI and Autonomous Technologies in the War in Ukraine and Implications for Strategic Stability,” CNA (September 2023). <https://www.cna.org/reports/2023/10/ai-and-autonomous-technologies-in-the-war-in-ukraine>. Accessed March 28, 2025.

633 A technology revolution refers to a fundamental change in the technical capabilities of instruments (drones, in this case) or the methods for using those instruments to grant capabilities. To be a revolution—as opposed to rapid evolution—the change must be a distinct departure from the pre-revolution technology.

634 R. Cargill Hall, “Reconnaissance Drones: Their First Use in the Cold War,” *Air Power History* 61, no. 3 (Fall 2024), pp. 20–27. <https://www.jstor.org/stable/26276490>. Accessed March 28, 2025.

635 Commercially available drones were also used extensively in the Armenia-Azerbaijan conflict, though the conflict was much smaller than the ongoing war in Ukraine. See Craig A. Reed and James P. Rife, “New Wrinkles to Drone Warfare,” U.S. Naval Institute (January 2022). <https://www.usni.org/magazines/proceedings/2022/january/new-wrinkles-drone-warfare>. Accessed March 28, 2025.

636 C. J. Chivers, “How Suicide Drones Transformed the Front Lines in Ukraine,” *The New York Times* (December 31, 2024), sec. Magazine. <https://www.nytimes.com/2024/12/31/magazine/drones-weapons-ukraine-war.html>. Accessed March 28, 2025.

Drone capabilities were steadily improving before 2022, and the conflict in Ukraine has likely accelerated the rate of improvement we have seen since then. However, the growing drone capabilities seen since 2022 so far represent an evolutionary—as opposed to a revolutionary—change in drones’ technical capabilities. Despite being used to an unprecedented degree from the earliest days of the war, the technical capabilities of drones did not change in February 2022. The drones used in the early days of the war were manufactured before the war began, and even today, most of the drones in use are iterative improvements of designs and concepts that predate the conflict, often by many years. Small commercial drones like the ones currently being used in Ukraine emerged as popular consumer products in the mid to late 2000s. Low-cost, purpose-built military drones began to emerge by the early to mid-2010s. The Turkish-made Bayraktar TB2, for instance, was introduced in 2014. Other, more primitive, examples of low-cost purpose-built military drones go back to at least the 1990s with Israel’s IAI Harpy drone. Improvements to drones’ technical capabilities since early 2022 have been rapid, but so far they do not reflect a revolutionary departure from the evolving capabilities seen before 2022.

The extensive use of drones has had at least three major impacts on the conflict. First, drones have narrowed the capabilities gap between the stronger and weaker actors in the conflict (Russia and Ukraine respectively) by granting the weaker actor capabilities they would not have otherwise. Unlike Russia, Ukraine has few traditional military assets capable of ISR and long-range strikes. By being relatively low cost and easy to acquire, drones have provided Ukraine with ISR and the ability to strike targets deep inside of Russia.⁶³⁷

Second, drones have reduced the time lag between spotting and attacking targets. Due to the high degree of real-time situational awareness provided by drones, the process of spotting a target and pinpointing its location is now extremely fast. The target can then be quickly attacked with drones acting as guided munitions or with non-drone weapons systems that need targeting information to be effective (e.g., artillery).⁶³⁸

Third, drones have made air defense more difficult. The conflict has shown that drones can penetrate highly contested air spaces. Existing anti-aircraft systems have only been moderately effective at shooting down larger drones, which have been used repeatedly by both sides to strike strategically significant targets over great distances in Ukraine and Russia.⁶³⁹ There also appears to be no hard counter for swarms of small, short-range attritable drones.⁶⁴⁰

Wargames before 2022

The following are three wargames conducted before February 2022 that made predictions about future conflict.

637 “War in Ukraine: Russia Accuses Ukraine of Attacking Oil Depot,” BBC News, (April 1, 2022), <https://www.bbc.com/news/world-europe-60952125>. Accessed March 28, 2025.

638 Kunertova, “The War in Ukraine Shows the Game-Changing Effect of Drones Depends on the Game.”

639 Ibid.

640 Konaev, “Tomorrow’s Technology in Today’s War: The Use of AI and Autonomous Technologies in the War in Ukraine and Implications for Strategic Stability.”

CNAS's Game of Drones

CNAS conducted a two-day wargame in October 2015 about aerial drone warfare.⁶⁴¹ The game was designed to examine how actors would use existing drone capabilities in near-future conflicts, whether the use of drones would be meaningfully different than the use of traditional airpower, and how drones would affect strategic-level behaviors like signaling, risk-taking, and escalation.

The wargame had four teams playing as fictitious actors that represented the roles of major powers, minor powers, and non-state entities. The teams played 12 scenarios meant to reflect the spectrum of modern conflicts, ranging from low-intensity and asymmetric warfare to major conventional engagements.⁶⁴² The scenarios were designed to push teams to employ drones for a diverse set of purposes, such as conventional standoff attacks, interventions in foreign wars, signaling resolve, information operations, conducting deniable attacks on sovereign territory, monitoring treaty compliance, and counterterrorism operations.

To respond to the scenarios, each team was given drones as well as conventional non-drone military assets. Each team's conventional and drone assets corresponded with those available to real-world major powers, minor powers, and non-state actors. The types of drones ranged from small commercial to high-end military models. The assets' capabilities were assumed to match those that have been publicly demonstrated.

CNAS' wargame report provides few details about the move-making process, but it appears that participants indicated how they would use their assets with open-ended responses. Adjudication was conducted by a white cell in the final 10 minutes of each move. No further details about the adjudication process are provided, but the brevity of the process suggests it was informal and based on the white cell's intuition.

Each of the two days concluded with a discussion among participants about whether and how drones affected their strategies and ability to achieve objectives. Importantly, the framing of these discussions did not assume that drones made a meaningful difference. Rather, the degree to which drones mattered was framed as an open question for the respondents to answer. The findings outlined by CNAS in their report were based on these discussions.

Overall, the CNAS wargame was remarkably prescient about the role drones would play in Ukraine. At the broadest level, the wargame correctly predicted that drones would have a profound impact in future conflicts and would improve the performance of smaller, less well funded military forces against the militaries of larger powers. Most of the wargame's specific predictions about how drones would be used at the operational level have also turned out to be correct. The wargame correctly predicted that:

1. Drones—particularly small attritable drones—would be used extensively as ISR platforms and precision strike weapons.
2. Drones would be used to capture video footage of attacks and atrocities that would be used in propaganda.

641 "Game of Drones - Proliferated Drones: Wargame Report," Center for a New American Security (June 29, 2016). <https://drones.cnas.org/reports/game-of-drones/>. Accessed March 28, 2025.

642 The games had up to four moves each.

The wargame also correctly identified key implications of drones being used extensively as ISR platforms and precision strike weapons. It predicted that drones would grant minor military forces ISR and precision strike capabilities they would not otherwise have. By doing so, drones would reduce the capabilities gap between major and minor military forces. It also predicted that drones would dramatically shorten the time between identifying a target and being able to eliminate it.

The wargame also made several predictions about the strategic-level impacts of drones. For the most part, these strategic-level predictions are not consistent with what we have seen in Ukraine so far:

3. Drones would lead to increased strategic risk-taking because of reduced tactical risks when using drones.
4. Drones would allow outside powers to intervene in a conflict while denying involvement.
5. Drone use by an external power would be interpreted as a sign of hesitancy and lack of resolve.

The war mostly contradicts Point 3 about drones leading to increased risktaking. There is no evidence that drones have increased the North Atlantic Treaty Organization's (NATO) risktaking in the conflict. If drones were increasing NATO's willingness to take risks, one would expect to see NATO using drones (but not manned aircraft) to carry out attacks in Ukraine or Russia. So far, however, NATO has not directly carried out any attacks in Ukraine or Russia.

As to whether drones have increased Ukraine or Russia's willingness to take strategic risks, the evidence so far has been weak. Ukraine has used drones to conduct strikes deep inside Russia, which involves at least a small degree of strategic risk (e.g., the attacks could conceivably provoke Russia to retaliate by using a nuclear weapon in Ukraine), but it is not clear that drones have meaningfully increased Ukraine's willingness to conduct these strikes given that it has also conducted strikes into Russia using manned platforms.⁶⁴³ For its part, Russia has carried out extensive gray zone tactics in NATO countries, including sabotage and attempted assassinations, which risk provoking NATO reprisals.⁶⁴⁴ Drones are among the tools Russia has used in these operations, but they are by no means the only tool they have employed.⁶⁴⁵ As with Ukraine's behavior, it is unclear that drones have made Russia more willing to take strategic risks than it would be otherwise.

The war also contradicts Point 4 because no outside powers have used drones to intervene in the conflict while denying involvement. At present, there is no evidence that drones in Ukraine are being covertly operated by outside powers. The United States and NATO have provided drones to Ukraine, and Iran has sold drones to Russia, but these outside actors have not denied their role in providing these drones. Regarding Point 5, the war has not produced clear evidence one way or the other, as outside powers have not operated drones in Ukraine on any meaningful scale.

643 "War in Ukraine."

644 Lara Jakes, "Drones, Exploding Parcels and Sabotage: How Hybrid Tactics Target the West," *The New York Times* (January 4, 2025). <https://www.nytimes.com/2025/01/04/world/europe/nato-attacks-drones-exploding-parcels-hybrid.html>. Accessed March 28, 2025.

645 Ellen Francis et al., "Finland Seizes Ship in Probe of Undersea Cable Damage," *The Washington Post* (December 26, 2024). <https://www.washingtonpost.com/world/2024/12/26/finland-russia-ship-undersea-cable-sabotage/>. Accessed March 28, 2025.

USAF's Wargame of Drones

The USAF conducted a wargame in 2020 in which the United States fought to repel a Chinese invasion of Taiwan.⁶⁴⁶ Aerial drones were among the air assets examined by the wargame. The game was played on a board with markers indicating the locations of military assets. It incorporated a high degree of technical detail, including performance characteristics of drones in service and under development. The wargame's format suggests that it used random draws from probability distributions to determine outcomes (e.g., whether a missile successfully shoots down a drone).⁶⁴⁷ Given its setting in the western Pacific, there are obvious differences between the circumstances depicted in this wargame and the war in Ukraine. Nevertheless, the wargame's drone-related findings are broadly consistent with what has been seen in Ukraine. The game's drone-related findings are summarized in the following three points:

1. Overall, the wargame found drones to be critically important in the conflict and it highlighted the usefulness of relatively low-cost attritable drones.
2. Drones can penetrate highly contested air spaces, and there is no hard counter to swarms of attritable drones.
3. There is significant differentiation between the roles of different classes of drones. Small attritable drones can operate in or near combat zones while larger drones are forced to operate at standoff distances.

RAND's Baltic Defense Wargame

The third pre-2022 wargame I examine is RAND's Baltic Defense game, which was run multiple times in 2014 and 2015.⁶⁴⁸ It depicts a Russian invasion of the Baltic. The game was highly structured. It had a game board on which players moved tokens representing military assets. Asset capabilities were based on demonstrated capabilities that have been seen in recent conflicts. Adjudication was done with random draws from probability distributions.

Unlike the two wargames discussed above, the RAND game did not explicitly incorporate drones as tools the players could use. Instead, the game implicitly accounted for the role of drones through the sensor-to-shooter performance characteristics it assigned to Russian artillery. The game was designed under the assumption that Russia would use drones as artillery spotters like they had in Syria and the Donbas after 2014, and that the drones would allow for sensor-to-shooter performance similar to what was observed in those conflicts.⁶⁴⁹ These assumptions are the game's implicit predictions about drone use in a near-future conflict with Russia: drones would play a relatively minor role in line with

646 Valerie Insinna, "A US Air Force War Game Shows What the Service Needs to Hold off — or Win against — China in 2030," *Defense News* (April 12, 2021). <https://www.defensenews.com/training-sim/2021/04/12/a-us-air-force-war-game-shows-what-the-service-needs-to-hold-off-or-win-against-china-in-2030/>. Accessed March 28, 2025.

647 The specifics of the adjudication process for this game are not publicly available.

648 David Shlapak and Michael Johnson, *Reinforcing Deterrence on NATO's Eastern Flank: Wargaming the Defense of the Baltics* (RAND Corporation, 2016). <https://doi.org/10.7249/RR1253>. Accessed March 28, 2025.

649 Gian Gentile et al., *Revisiting RAND's Russia Wargames After the Invasion of Ukraine: Summary and Implications*, RAND Corporation (2023). <https://doi.org/10.7249/RRA2031-1>. Accessed March 28, 2025.

what had been observed in Syria and Donbas. These predictions are inconsistent with the events in Ukraine since early 2022.

Of course, the RAND wargame was not designed to make predictions about the role of drones specifically. It was intended to predict how a Russian invasion in eastern Europe would play out. It was set in the Baltics, and in the leadup to February 2022, it reflected the assumptions of many analysts about how a Russian invasion of Ukraine would unfold.⁶⁵⁰ The game predicted a rapid Russian victory where Russia would quickly overwhelm the defending forces, suffer few casualties, and occupy the defender's capital before NATO could assist the defender. These predictions turned out to be incorrect in Ukraine, where Russia's initial advance towards Kiev quickly stalled and its subsequent advances have been costly and glacially slow.

The poor predictions from this wargame illustrate how critical a wargame's underlying assumptions are to the validity of its results. The game's poor predictions resulted from the assumptions it made about Russian military effectiveness combined with a game structure that did not incorporate many of the key factors that have shaped the conflict in Ukraine. Drones were one important factor the game did not account for, and there were many others that—to their considerable credit—the game's authors have reflected upon.⁶⁵¹

The wargame's poor predictions demonstrate the importance of using purpose-built games to study technology competition. Its faulty assumptions about drones and military effectiveness were based on historical analysis and did not draw on wargames that were designed to examine technology competition. While historical analysis can offer important insights about the future in the form of long-term trends and reoccurring patterns, it is not well suited for anticipating innovations in strategies and tactics.⁶⁵² The RAND wargame may have offered better predictions about Russia's invasion if its assumptions had been informed by purpose-built technology competition games as opposed to relying entirely on historical analysis.

Capabilities and Limitations of Wargaming

The three wargames discussed in this chapter illustrate the insights wargaming can provide in the context of technology competition. They also demonstrate the limitations of wargaming. The CNAS and USAF wargames demonstrate that wargames can make useful predictions about the evolution of technological methods—i.e., they can predict how technological instruments like drones will be used. These predictions can be made based on existing technologies with established capabilities like the drones in the CNAS wargame. They can also make predictions that involve emerging technologies with speculative capabilities like some of the drones in the USAF wargame. In the latter case, the accuracy of some of the game's more specific findings would depend on whether the speculative capabilities assumed by the game reflect reality, which is not currently known.

650 Eliot A. Cohen and Phillips O'Brien, "The Russia-Ukraine War: A Study in Analytic Failure," Center for Strategic and International Studies (September 2024). <https://www.csis.org/analysis/russia-ukraine-war-study-analytic-failure#:~:text=Eliot%20Cohen%20and%20Phillips%20O'Brien%20examine>. Accessed March 28, 2025.

651 Gentile et al., *Revisiting RAND's Russia Wargames After the Invasion of Ukraine*.

652 Antonio Calcara et al., "Why Drones Have Not Revolutionized War: The Enduring Hider-Finder Competition in Air Warfare," *International Security* 46, no. 4 (Spring 2022), pp. 130–71. <https://direct.mit.edu/isec/article/46/4/130/111172/Why-Drones-Have-Not-Revolutionized-War-The>. Accessed March 28, 2025.

The predictions from wargames can be both accurate and unintuitive. The CNAS wargame was run in 2015 and made remarkably accurate predictions about how drones would be leveraged in a conflict that began seven years later. Its predictions were not obvious at the time. Drone use in 2015 was mostly restricted to a comparatively small number of large, expensive surveillance platforms operated by high-end militaries, and many contemporary observers argued that ongoing drone development would continue to yield incremental improvements in capabilities without leading to revolutionary changes in how wars would be fought.⁶⁵³ Remarkably, the CNAS wargame made its insights about the transformative impact of drones even before the 2020 Armenia-Azerbaijan conflict over Nagorno-Karabakh, in which drones played a prominent, well-publicized role that foreshadowed their ubiquitous use in Ukraine.⁶⁵⁴

The RAND wargame illustrates that wargames do not predict technical capabilities. Rather, wargames incorporate technical capabilities as assumptions. Predictions and other findings from wargames are conditional on the wargame's assumptions being correct. The RAND wargame's prediction of a rapid Russian victory was premised on Russia's technical capabilities being greater than they really were.

The three wargames also demonstrate that the specifics of a wargame's scenario are often not especially important for the quality of insights they offer about technology competition. The CNAS and USAF wargames were based on scenarios that bore little resemblance to Ukraine, yet many of their insights about drone use are consistent with what we have seen in the conflict.

Features of Good Wargames

A comparison of the three games suggests a series of design features necessary for a wargame to provide helpful predictions or other meaningful insights regarding technology competition. First, a wargame should be focused on a particular technology of interest as opposed to presenting players with an open-ended toolset. The CNAS and USAF wargames could make predictions about drones because their designs limited players' toolsets to a defined set of drone types and other related air assets. Restricting the players' toolsets in this way meant that players' moves reliably reflected how they thought drones should (or should not) be used. As a result, the games provided enough data to the researchers to form generalizations about drone use; most player decisions involved drone use in some form, and even those that did not reflected conscious decisions by the players to forgo drones in favor of other related assets.⁶⁵⁵ If the games had left the toolset open-ended so that players could leverage whatever tools they could think of, the tools employed would likely have been extremely disparate. Such an open-ended approach may be appropriate for preliminary research (e.g., to help identify potential tools that should be examined in future research), but such disparate responses would limit the researchers' ability to form meaningful conclusions about the use of any specific tool. An implication of this point is that no one wargame can encapsulate technology competition. Rather,

653 Ibid.

654 Reed and Rife, "New Wrinkles to Drone Warfare."

655 Having sufficient data about the variable of interest (e.g., drone use) is essential for both qualitative and quantitative analysis. *Data* is not restricted to numeric values; it also includes oral and written responses from wargame participants.

technology competition must be disaggregated into constituent parts (e.g., specific technical domains or limited combinations of domains) and studied with multiple dedicated wargames.

Second, the technology of interest needs to be explicitly incorporated as a tool (or set of tools) with defined capabilities that the players can use. The CNAS and USAF wargames did not ask players how they would use drones as a general concept. Rather, they told players they had specific types of drones with clearly defined capabilities and then asked the players how they would use them. This design choice ensured that all players shared a common understanding of the tools at their disposal.

Third, games should focus on asking players how they would use the provided tools, not simply whether they would use them. The insights wargames can provide about technology center on the methods for using instruments. To play to their strength, wargames should therefore ask questions that elicit details about methods. Wargames should not limit themselves to binary choices about whether to use a specific technology.

Fourth, the tools wargames provide players should not be limited to the technology of interest. The CNAS and USAF wargames gave players both drones and non-drone tools. If they had only provided drones, drones playing a prevalent role in the game would have been an engineered outcome because players would have had no alternatives. When players have a range of tools with overlapping capabilities, the degree to which they use a specific tool provides information about the tool's importance and desirability relative to alternatives. In practice, it is also rare for any one instance of technology to be used in isolation. Providing players with a range of tools has the added benefit of making the wargame more realistic and increases the potential for players to determine innovative ways for using the technology of interest.

Fifth, wargames do not need to adhere to any particular format to yield useful insights about technology competition; the CNAS and USAF wargames were both successful, despite having radically different design philosophies.

Improving Wargaming

The wargames examined in this chapter demonstrate that well-designed wargames can lead to accurate, counterintuitive insights about drone use. However, these insights have so far been limited primarily to the operational level. The USAF game did not make strategic-level predictions, and the few such predictions offered by the CNAS game were not consistent with what we have seen in Ukraine so far. The insights from more recent drone-related wargames have been similarly focused on the operational level. For instance, Concepcion et al.'s forthcoming study leverages operational-level wargaming to identify specific mixes of drone technologies that would provide Taiwan with the most cost-effective defense against an attempted Chinese invasion.⁶⁵⁶

The dearth of strategic-level insights from these games is due to their operationally-focused designs. The USAF game only asked players to make operational decisions with the goal of defeating their adversary in combat. It did not require players to make decisions about strategic-level matters like escalation and signaling to allies. Thus, its design simply did not allow the game to offer insights about drones' impact on strategic-level decisions. The CNAS wargame's more loosely structured

656 John Concepcion et al., "Fortress Taiwan: Mapping Defense Strategies Through Wargaming" (2024).

design allowed players to address the strategic level to some extent, but the scenarios (along with the bulk of the findings in the after-action report) were operationally focused.⁶⁵⁷

There are only a few strategically focused wargames about drones, and they were not designed to produce insights about drone-use methods. These studies use experimental designs that incorporate drones as treatments but not as tools players can use. For example, Lin-Greenberg's *Wargame of Drones* compared the retaliatory decisions of two groups of players. The first group was told that an adversary had shot down a drone and the second group was told that the adversary had shot down a manned aircraft.⁶⁵⁸ This approach determines how a treatment (e.g., a drone as opposed to a manned aircraft being shot down) affects player decisions (e.g., whether to retaliate).⁶⁵⁹ However, it does not yield insights about the drone-use methods that strategic-level leaders may employ.

To better understand drone-use methods that strategic-level leaders may employ, wargames must be intentionally designed for this purpose. They need to incorporate drones as tools players can use and require players to make one or more types of strategic decisions in each move. For instance, a wargame that examines escalation could present players with a rapidly escalating crisis and provide a range of tools the players can use to manage the escalation. The tools could include different types of drones as well as a selection of other military, diplomatic, or economic options. Such a wargame would not need to be especially sophisticated. Fundamentally, all a wargame needs to do is present players with a problem, a set of tools, and questions about how they will use the available tools to address the problem. Wargame design does not need to be complicated to be effective.

657 It is unclear whether the operationally-focused design of the CNAS wargame is why its strategic-level predictions have mostly not held up. However, a more strategically focused game would have at the very least produced predictions that were more nuanced and more fully explored. It is plausible that more nuanced and detailed versions of the same strategic-level predictions in the CNAS report would have better reflected the post-2022 Ukraine conflict. For instance, it may be that actors tend to use drones to deny involvement only under conditions that are not present in Ukraine.

658 Erik Lin-Greenberg, "Wargame of Drones: Remotely Piloted Aircraft and Crisis Escalation," *Journal of Conflict Resolution* 66, no. 10 (November 2022), pp. 1737–65. <https://doi.org/10.1177/00220027221106960>. Accessed March 28, 2025.

659 The study found that players are more likely to retaliate when a manned aircraft is shot down than when a drone is shot down.

Strategic Latency, Technology Competition, and the Quest for Strategic Advantage

Zachary S. Davis

The Age of Technology is reshaping nearly every aspect of modern life. Like previous industrial and technological revolutions, this new era is all encompassing, affecting the lives of individuals, the societies they live in, and the geopolitical state of the world. Nothing is left untouched by the march of technological progress. Adding to the revolutionary nature of this technological onslaught, the changes brought by technology seem to be happening at breakneck speed. Everyone is scrambling to take advantage of the changes, but it's hard to tell who is winning. How do we know who is winning the competition for strategic advantage?

The term Strategic Latency describes technological developments that have inherent potential to shift the global balance of power. Using the word “strategic” distinguishes the natural march of technological progress from the developments in science and technology that can radically reshape the future. Examples of technologies with strategic effects include electricity, telephones, atomic weapons, long-range missiles, microchips, and artificial intelligence. Strategic advantage is achieved when a nation exploits the latent potential of technology to increase its power relative to other countries, who are also competing for advantage in the international system. Figuring out the next technologies with latent potential to change the world, therefore, can be a matter of survival. There are winners and losers.

Anticipating such strategic effects, nations are compelled to harness the latent power of technology to serve their security interests. Defense planners (and investors) try to anticipate significant science and technology (S&T) trends and breakthroughs that loom on the horizon. Nobody wants to be left behind. The United States can either compete for strategic advantage or face the consequences.

The Future of Technology

Yogi Berra reminded us that “Prediction is hard, especially about the future.” Futurists such as Alvin Toffler, George Orwell, Jules Verne, Arthur C. Clark, and Issac Asimov envisioned how technology might transform the future of humanity. Many of their predictions have come to pass — space travel, lasers, mass communication, and high-performance computers among them. One thing they did not highlight was nation-state competition for technology advantage. Prediction is hard, but foresight about significant trends is possible. Sometimes we can recognize latent potential looming on the horizon and figure out how to tap into it.

Here at Lawrence Livermore National Laboratory, we are in the business of advancing the frontiers of science and technology and applying new technologies to national security. We push the frontiers of science to advance U.S. national security interests, broadly defined to include deterrence, defense, space, global health, energy, and other issues. The mission of the lab (and the other government laboratories) is to ensure that our country does not suffer from a strategic surprise that leaves us at a dangerous disadvantage. While the Lab's mission has focused on nuclear weapons, the development

of these complex systems has spun off numerous related technologies, including advancements in high-performance computing, materials science, and biology. Latent potential is often discovered in the process of pursuing other objectives. Investments in science regularly produce unexpected benefits. Spinoffs are normally unexpected and harder to predict.

What are the next world-changing technologies? Quantum computing and fusion energy appear to be poised to have strategic impact, although the timing remains uncertain. Our previous studies of strategic latency highlighted the catalytic nature of scientific breakthroughs.⁶⁶⁰ More often than not, a combination of supporting technologies and synergistic circumstances coalesce to produce scientific breakthroughs and opportunistic applications. Examples include the convergence of atomic bombs and long-range missiles, high-performance computing and genetic engineering, and the combination of microchips with personal electronics. Such convergences often occur from serendipitous events, making them even harder to predict than the expected trajectories of visible scientific trends.

The march of progress has many twists and turns and often goes in unexpected directions. Science is no exception. Latency is exploited when human needs create demands and markets. However, while necessity is the mother of invention, curiosity, creativity and happenstance also play a role in birthing new technologies. So does politics. Innovation is a natural phenomenon that is exceedingly difficult to force or predict. Strategic advantage is hard to predict, even for those who are trying to achieve it.

Technology and National Security

As technology advances, the security dilemma in international relations dictates that national capabilities will be viewed as threatening by potential adversaries. Inherent in this concept is the idea of competition. No nation wants to be vulnerable to the technological capabilities of an adversary, whether it's fear of a surprise attack in the form of a "bolt from the blue" as was the case with Pearl Harbor, or a creeping "frog in the pot" erosion of competitive advantage. Throughout the Cold War, innovations in nuclear weapons and delivery systems drove an arms race, with worst case scenarios fueling a tit for tat cycle of competition. Even perceptions of latent technological advantage were enough to trigger counter balancing actions. This action-reaction dynamic is carefully examined in several chapters in this volume. Competition is woven into the fabric of the anarchic international system.⁶⁶¹

Technology competition in international politics reflects national aspirations for power, including military, economic, and cultural manifestations of hard and soft power. Technology is a primary expression of power. And since power is not equally distributed among nations, not all countries are motivated or able to compete in the race for technological advantage. Strategic competition occurs among great powers who fear one another, and less often between nations who maintain good relations. Technology competition is a fundamental aspect of the perpetual "balancing and

660 Zachary Davis, Ronald Lehman, and Michael Nacht, *Strategic Latency and World Power: How Technology is Changing Our Concepts of Security* (Livermore, CA: Lawrence Livermore National Laboratory, 2015); Zachary S. Davis and Michael Nacht, *Strategic Latency: Red, White and Blue: Managing the National and International Security Consequences of Disruptive Technologies* (Livermore, CA: Lawrence Livermore National Laboratory, 2018); Zachary S. Davis, Frank Gac, Christopher Rager, Phillip Reiner, and Jennifer Snow, *Strategic Latency Unleashed: The Role of Technology in a Revisionist Global Order and the Implications for Special Operations Forces* (Livermore, CA: Lawrence Livermore National Laboratory, 2021).

661 Hedley Bull, *The Anarchic International Society: A Study of Order in International Politics* (New York, NY: Columbia University Press, 1977).

bandwagoning” that describes state behavior in the international system.⁶⁶² Those who face security threats and don’t have the technological means to defend themselves must either acquire the necessary tools or align with someone who does. Allies and alliances are most often forged around sharing the military and economic aspects of technology. And since there is no such thing as absolute security, the struggle for power is constant. Technology is power.

Technology Competition Among Great Powers

In the heat of the Cold War, many Americans believed that the Soviet Union was winning the arms race. Perceptions of Sputnik, the bomber gap, and the missile gap spurred politicians and defense planners to accelerate investments in science and technology. Fear of Reagan’s Star Wars concepts and prospects for U.S. missile defenses rattled Soviet officials. Both sides feared the other would use their technological advantage to attack and relegate them to the ash heap of history. Ultimately, American technology and the economy behind it played a major role in the demise of the Soviet Union. While spending the Soviet Union into bankruptcy was not the primary objective of U.S. policy, and the collapse of the Soviet empire was not the “end of history,” there was a clear winner and a clear loser in the Cold War. America’s strategic advantage was decisive, but temporary. Russia remains relevant as a strategic disruptor but is not a serious contender for overall technology advantage. Its competitive position is derived from natural resources, nuclear weapons, and cunning manipulation of global perceptions.

The Cold War, however, may not be the best guide for understanding the dynamics of contemporary technology competition. Technology is advancing faster and is more available than ever before. The democratization of technology has reduced the controls once held by governments and large institutions. More countries, private companies, organizations, and even individuals have access to cutting edge technologies, including strategically latent technologies such as artificial intelligence (AI), additive manufacturing, and genetic engineering.⁶⁶³ Global markets rapidly translate the latest scientific breakthroughs into consumer goods and services. In the military sphere, commercial satellite imagery, AI, drones, and new materials are changing the operational environment and the economics of warfare.⁶⁶⁴ The raw materials required for strategic weapons are mostly available to those who seek advantage. Strategic advantage is achieved by those who can rapidly translate S&T into military and economic forms of power. Russia has the resources but lacks the necessary investments and markets.

Competition with China is Different

Whereas the United States relied on its industrial base, free markets, alliances, and public investments to become the world leader in science and technology, China exploits the democratization and globalization of technology to fuel its emergence as a global power. The Soviet

662 Steven Walt, *The Origins of Alliances* (Ithaca, NY: Cornell University Press, 1987).

663 Zachary Davis and Michael Nacht, “Terror Tech: How Will Emerging Technologies Be Used by Terrorists to Achieve Strategic Effects?” in *Strategic Latency: Red White and Blue, Managing the National and International Security Consequences of Disruptive Technologies* (Livermore, CA: Lawrence Livermore National Laboratory, 2018).

664 *Strategic Latency Unleashed*; Christian Brose, *The Kill Chain: Defending American in the Future of High-Tech Warfare* (New York, NY: Hachette Books, 2020).

Union heaped massive human and material resources on its military industrial complex to compete with the United States. It proved unsustainable. China is different.

China harvests the accumulated S&T accomplishments of humanity for its economic and scientific advancement, recycling them into its own unique brand of industrial policy.⁶⁶⁵ With its unmatched human and material resources and the administrative apparatus of the Chinese Communist Party to manage this colossus, China is poised to assert leadership in many critical areas of technology competition.

Like all countries, China faces formidable challenges in its ability to exploit the latent potential of S&T and apply it to military purposes. Like U.S. Containment policy that sought to exacerbate internal fractures within the Soviet system, there may be opportunities to exploit China's domestic struggles. However, the key to U.S. technology leadership has been the vibrant private sector that profits from technology sales as well as from the sales and influence derived from military products. The Soviet Union relied on state-owned enterprises that were entirely dependent on government funds. Russia still struggles to find markets for its advanced technologies and suffers from brain drain of its top scientific talent.⁶⁶⁶ India is trying to evolve beyond reliance on state-owned enterprises to fuel innovation and investment. Technology advantage thrives on free markets.

China has developed a unique approach to compete for strategic advantage. Efforts to control strategic materials and develop their own semiconductors illustrate Beijing's intentions to vie for control of the basic ingredients of the technological revolution and to cultivate markets for the underlying dual-use technologies and materials that support Beijing's global aspirations. China's wholesale theft of intellectual property and immense and illicit acquisitions of data are components of a larger plan to establish China as the preeminent power in S&T.⁶⁶⁷ The plan includes using artificial intelligence to query the data sets they are appropriating from every sector of global society (governments, companies, universities, organizations, the internet of things...), and to feed the insights they gain into their own S&T development. This alternative to relying on human ingenuity and free markets takes advantage of global connectivity to support China's national objectives. Furthermore, China's civil-military fusion policy is designed to ensure the transfer of cutting-edge S&T to military applications. Moreover, controlling access to Chinese markets adds additional leverage to China's relationships with global technology companies.

It is hard to predict if this novel top-down approach will work to give China meaningful technological advantage. However, in some specific areas of technological competition, the trends suggest it will. In the emerging era of nuclear competition, for example, China appears to have assembled the ingredients it needs to achieve Chairman Xi's ambitious goals to catch and surpass the

665 Brandon Williams, "The Innovation Race: US-China Science and Technology Competition and the Quantum Revolution," Wilson Center, October 2023. <https://www.wilsoncenter.org/publication/innovation-race-us-china-science-and-technology-competition-and-quantum-revolution>. Accessed April 9, 2025.

666 Zachary Davis, Frank Gaç, and Michael Nacht, and Joey L. Ching, *Strategic Latency and Warning: Private Sector Perspectives on Current Intelligence Challenges in Science and Technology*, Center for Global Security Research (January 2016). https://cgsr.llnl.gov/sites/cgsr/files/2024-08/StrategicLatencyReport_0.pdf. Accessed April 9, 2025.

667 Rush Doshi, *The Long Game, China's Grand Strategy to Replace American Order* (New York, NY: Oxford University Press, 2021).

nuclear capabilities of Russia and the United States.⁶⁶⁸ If Chairman Xi can weather China's domestic discontents, Beijing could surpass the United States to assert strategic advantage in several critical fields and claim the mantle of world leader in science and technology.

Winning and Losing

Does it matter if China asserts some degree of strategic advantage in S&T? Putting aside the staggering costs of China's wholesale theft and espionage against the United States,⁶⁶⁹ how would Chinese strategic advantage affect U.S. security?

If China's goal was to wield S&T to secure its role in a stable and sustainable multi-polar balance of global power, as many hoped would occur at the outset of globalization era, accommodations might be possible. This does not appear to be the case.⁶⁷⁰ Chairman Xi has elaborated goals and implemented policies aimed at asserting preponderant power for the CCP, including territorial aggression against his neighbors.⁶⁷¹ The goal appears to be for China to claim economic dominance and to use its economic power to shrink U.S. global economic influence. S&T is primarily a means to economic power, which is the precursor of military power.

Stable multi-polar nuclear deterrence might be acceptable, but not if Xi's goal is to use military and nuclear threats to intimidate U.S. allies and prevent the United States from continuing its longstanding commitments in the Indo-Pacific region. Beijing's opacity about its defense policies and especially its nuclear posture fuels worst case scenarios reminiscent of the Cold War. Furthermore, China's alignment with Russia, Iran, North Korea, and other revisionist, authoritarian regimes, backed by its paid partnerships in Africa and elsewhere, appears to be intended to overthrow the "rules-based" global order that was instituted with American leadership in the wake of World War II. Other elements of the PRC strategy include "frog in the pot" efforts to erode the role of the U.S. dollar in global commerce and replace U.S. cultural influences around the world with Chinese themes and narratives.⁶⁷² In light of the aggressive nature of these challenges, the United States would be unwise to ignore the threats posed by China's quest for strategic advantage, which is designed to undermine U.S. global influence.

668 U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China* (2022). <https://media.defense.gov/2022/Nov/29/2003122279/-1/-1/1/2022-MILITARY-AND-SECURITY-DEVELOPMENTS-INVOLVING-THE-PEOPLES-REPUBLIC-OF-CHINA.PDF>. Accessed April 9, 2025.

669 Glenn Chafetz, "The U.S. Needs a More Accurate Estimate of China's Commercial Espionage," *The Cipher Brief* (October 18, 2024). https://www.thecipherbrief.com/column_article/the-u-s-needs-a-more-accurate-estimate-of-chinas-commercial-espionage (accessed April 9, 2025); Tom Lyons, "Why Do We Tolerate Beijing's Belligerence?" *The Wall Street Journal* (October 21, 2024), <https://www.wsj.com/opinion/why-do-we-tolerate-beijings-belligerence-communist-party-theft-e99c2b7c> (accessed April 9, 2025).

670 Rush Doshi, *The Long Game, China's Grand Strategy to Replace American Order*; *Ibid*.

671 Academy of Military Science, Military Strategy Department, *The Science of Military Strategy*, Translated by China Aerospace Studies Institute, U.S. Air Force, Air War College. <https://www.airuniversity.af.edu/Portals/10/CASI/documents/Translations/2022-01-26%202020%20Science%20of%20Military%20Strategy.pdf>. Accessed April 9, 2025.

672 Zachary S. Davis and Marshall Monroe, "One Belt, One Movie: China's Campaign to Cancel America's Cultural Dominance and Assert Cultural Narratives," Department of Defense, SMA Perspectives (January 2021). <https://nsiteam.com/social/one-belt-one-movie-chinas-campaign-to-cancel-americas-cultural-dominance-and-assert-new-narratives/>. Accessed April 9, 2025.

Unleashing Strategic Latency

Fears of Soviet advantage inspired investments in defense-related technologies that created Silicon Valley and established American dominance in S&T for decades.⁶⁷³ It is that era of dominance that is now being challenged—and must be reimagined. What is the purpose of competing with China? How do we know who is winning?

Previous books on strategic latency published by the Center for Global Security Research (CGSR) examined the efforts to reform U.S. defense industrial processes to adapt to the new era of globalized and multi-polar, multi-domain competition.⁶⁷⁴ We have highlighted the role of national labs in driving innovation and examined U.S. government efforts to build public-private partnerships to provide warfighters with cutting edge technologies.⁶⁷⁵ Others have contributed to this increasingly urgent call for reforms in the way the United States procures technology for its national defense.⁶⁷⁶ Many of these studies focus on the China S&T challenge, including several works of fiction that portray the terrible consequences of China wielding technology advantages in future conflicts with the United States.⁶⁷⁷ The old ways of competing are not sufficient, and the new concepts for public-private partnerships are not yet able to meet the challenge of reasserting America's strategic advantage. Technology and geopolitics are outpacing our old ways of competing.

Ironically, many of the technology companies whose products originally supported U.S. national defense have shifted their focus to global consumer markets. The companies that produced the microchips that made the second and third “offset” military capabilities now serve other masters. They are now focused on global markets for consumer goods like phones, computers, entertainment, robotics, and biotech. The manufacturing that gave us strategic advantage has moved on, and it has been difficult to persuade them to reprioritize U.S. national security over shareholder value. China, in fact, looms large in their manufacturing and market projections.

A combination of economic, political, and social forces has combined to render our defense industrial base incapable of producing the defense systems needed to compete with a rising China. Whether it's shipbuilding (especially submarines needed for AUKUS⁶⁷⁸), munitions (for Ukraine and

673 Margaret O'Mara, *The Code: Silicon Valley and the Remaking of America* (New York, NY: Penguin Books, 2019).

674 Davis et al., *Strategic Latency and World Power*; Davis et al. *Strategic Latency Red, White and Blue*; *Strategic Latency Unleashed*; *Ibid.*

675 Lisa Owens Davis, “Moving at the Speed of S&T: Calibrating the Role of National Laboratories to Support National Security,” in *Strategic Latency Red, White and Blue*, Zachary S. Davis and Michael Nacht, eds. (Livermore, CA: Lawrence Livermore National Laboratory), pp. 233-247; Frank Gac, Timothy Grayson and Joseph Keogh, “What Works? Public Private Partnerships for Development of National Security Technology,” in *Strategic Latency Red, White, and Blue*, Zachary S. Davis and Michael Nacht, eds. (Livermore, CA: Lawrence Livermore National Laboratory), pp. 202-232.

676 Tai Ming Cheung and Thomas G. Mahnken, *The Decisive Decade: United States–China Competition in Defense Innovation and Defense Industrial Policy in and Beyond the 2020s*, Center for Strategic and Budgetary Assessments (May 22, 2023). [https://csbaonline.org/uploads/documents/CSBA8352_\(Decisive_Decade_Report\)_FINAL_web.pdf](https://csbaonline.org/uploads/documents/CSBA8352_(Decisive_Decade_Report)_FINAL_web.pdf). Accessed April 9, 2025.

677 Peter Singer and August Cole, *Ghost Fleet: A Novel of the Next World War* (New York, NY: First Mariner Books, 2016); James Stavridis and Elliot Ackerman, *2034: A Novel of the Next World War* (New York, NY: Penguin Books, 2022); Zachary S. Davis, *Above Scorched Skies: A Story of Modern Warfare and World Power* (Livermore, CA: Center for Global Security Research, Lawrence Livermore National Laboratory, 2024).

678 The trilateral security partnership between Australia, the United Kingdom, and the United States.

Taiwan), or nuclear “pits” (the guts of a nuclear weapon),⁶⁷⁹ U.S. defense manufacturing is shrinking while China’s is growing.⁶⁸⁰

While competition with the Soviet Union was different, there are important lessons to be drawn from the Cold War. For example, U.S. government investments succeeded in advancing U.S. supremacy in S&T, and the spin-offs have been paying huge dividends for the American economy.⁶⁸¹ These investments were channeled through defense budgets, supported by Congress and successive presidents. Our response to strategic warnings sounded by Sputnik, the Missile Gap, and the arms race was to funnel billions into research and development (R&D). Although notoriously difficult to measure, U.S. R&D budgets have declined relative to China’s R&D spending, and private sector R&D often does not translate into national security applications.⁶⁸² Innovative entities such as In-Q-Tel and Defense Innovation Unit are not enough. Although they are the vital engine of prosperity and progress, free markets are not designed to serve America’s foreign policy objectives.⁶⁸³ That is the job of policy. Moreover, the warnings of Presidents Eisenhower and Biden about the dangers of too much power being concentrated in the hands of a privately held military-industrial-technological cabal have special relevance in this regard.

To compete effectively and to maintain a thoughtful degree of strategic advantage, the United States must make significant increases in R&D budgets and make new investments in the defense industrial base. To compete in the current geopolitical environment, we need to be able to produce ships, submarines, ammunition, and nuclear weapons in a timely manner. In addition to the creation of jobs for a reinspired workforce, such an infusion of resources would also create opportunities to shift priorities to produce faster, more automated, and resilient weapons needed for the new age of modern warfare and at the same time reform the broken Department of Defense (DOD) procurement and acquisition bureaucracies.⁶⁸⁴ One of the big payoffs from the Cold War investments came from the educational opportunities that were funded through defense spending. China, it should be noted, is pouring billions into STEM⁶⁸⁵ education as part of its plan to assert strategic advantage. Education can make or break the quest for strategic advantage.

679 Bruce T. Goodwin, *Nuclear Weapons Technology 101 For Policy Wonks* (Livermore, CA: Lawrence Livermore National Laboratory, 2021).

680 Madelyn R. Creedon et al., *America’s Strategic Posture: The Final Report of the Congressional Commission on the Strategic Posture of the United States* (October 2023). <https://www.ida.org/-/media/feature/publications/a/am/americas-strategic-posture/strategic-posture-commission-report.ashx>. Accessed April 9, 2025.

681 O’Mara, *The Code*; Ibid.; Brandon Kirk Williams, “America’s Past Offers the Model for Topping China in Science and Technology,” *The Washington Post* (April 14, 2022), <https://www.washingtonpost.com/outlook/2022/04/14/americas-past-offers-model-topping-china-science-technology/> (accessed April 9, 2025).

682 National Science Foundation, Science and Engineering Indicators, “Research and Development: U.S. Trends and International Comparisons,” (n.d.). <https://ncses.nsf.gov/pubs/nsb20246/cross-national-comparisons-of-r-d-performance>. Accessed April 9, 2025.

683 Matt Kaplan and Michael Brown, “The Private Sector on the Frontline: Big Tech and the Blurring of Commercial and Security Interests,” *Foreign Affairs* (January 31, 2025). <https://www.foreignaffairs.com/united-states/private-sector-frontline>. Accessed April 9, 2025.

684 Brose, *The Kill Chain*; Ibid.

685 Science, Technology, Engineering, and Mathematics.

To secure the required degree of strategic advantage for the emerging global nuclear order, the U.S. must fully implement the planned modernization of DOE⁶⁸⁶/NNSA⁶⁸⁷ infrastructure and make sure that the modern arsenal is “fit for purpose.”⁶⁸⁸ Modernization of the nuclear enterprise is also necessary to satisfy the extended deterrence requirements of U.S. allies, which is a key component of global nuclear order.⁶⁸⁹ Here too, the opportunity exists to replace Cold War manufacturing and outdated information systems throughout the nuclear complex with cutting edge manufacturing and production methods.

Renewed investments and a clear sense of mission are also critical ingredients for recruiting an inspired future workforce. Competing in nuclear weapons is one area where the Cold War model of funneling S&T investments through national security budgets still makes sense, and the spinoffs would recirculate within the national security S&T community. Stimulating innovation in other areas of national security technology beyond the nuclear enterprise, however, will require a strong consensus and commitment of funds to boost competitiveness in other sectors, including education.

Final Thoughts: Why Compete?

America’s place in the world is changing. The power we once held is being challenged. Our strategic advantages are declining relative to the rise of China, India, the BRICS, and the new alliances and coalitions that are forming to counter American power. Yet our vital interests remain steady, even while our adversaries and allies adjust to the new geopolitical dynamics. Technology is power, and technological advantage is an essential part of a strategy designed to protect our interests. Our choices are to compete or fall behind and be forced to accommodate the aggressive designs of our adversaries. As Thucydides described it in *The Peloponnesian Wars*, “The strong do what they can and the weak suffer what they must.”

Deterrence vis-à-vis the China-Russia-Iran-North Korea nuclear alliance demands a robust demonstration that we have the will and capability to compete. Perceptions matter. Evidence of our commitment to compete will be measured by the resources we devote to exploiting strategic latency. Failure to compete would fulfill the mistaken narratives about American decline. Choosing to compete will lay the foundation for a new era of American predominance in science and technology.

686 Department of Energy.

687 National Nuclear Security Administration.

688 Creedon et al., *America’s Strategic Posture*; Brose, *The Kill Chain*.

689 Brad Roberts, *Fit for Purpose? The U.S. Strategic Posture in 2030 and Beyond*, (Livermore, CA: Lawrence Livermore National Laboratory, 2020); *Ibid*.

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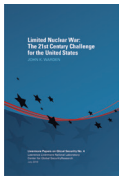
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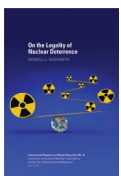
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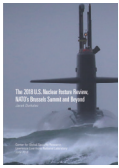
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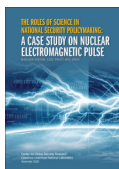
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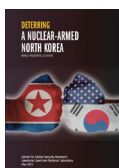
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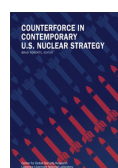
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