Under Pressure: Adversary Circumvention and Innovation Under U.S. Sustained Technological Denial

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Introduction

The United States has long employed export controls and sanctions as instruments of economic and national security strategy. While policymakers impose these policies to safeguard the U.S. technological competitive advantage and to limit the transfer of dual-use goods to antagonistic regimes, economic restrictions have proven unable to completely halt adversarial ambitions. Instead, states attempt to develop workarounds to circumvent U.S. policy, including theft, coercive partnerships, and the diversion of commercial supply chains. In some cases, states build domestic capacity to "innovate around" economic restrictions.[2]

In this paper, I address the research questions: How do states innovate or adapt in the face of sustained technological denial? Which United States economic restrictions are most effective in denying adversary innovation and circumvention? In this paper, the term "sustained technological denial" refers to the prolonged imposition of one or more economic policies (namely through sanctions and export controls) to restrict an adversary's access to specific goods or services. I argue that the most effective U.S. economic policies target specialized inputs, intermediary goods, and advanced machinery—particularly those with explicit military applications—within supply chains where the U.S. maintains significant leverage. This research contributes to existing literature on economic restrictions by comparing three distinct technology domains through a single analytic framework. In highlighting the importance of economic restrictions in creating qualitative capability limits, rather than material scarcity, this research reframes export-control outcomes in terms of strategic delay.

The United States employs economic restrictions, or tools that limit trade, financial transactions or other economic activities, predominantly in the form of sanctions and export controls. The United States defines sanctions as "the deliberate, government inspired withdrawal, or threat of withdrawal, of customary trade or financial relations," and sanctions have become a favored tool of

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[2] Caroline Wesson, "Innovating Around Export Controls Under Technology Competition: The Case of China and Advanced Semiconductors," in Kimberly Peh and Michael Albertson, ed., *In Search of Strategic Advantage: Understanding The Landscape of Technology Competition* (Livermore, CA: Center for Global Security Research, November 2025), pp. 51-73.

policymakers in responding to international challenges.[3] Sanctions, often authorized via executive order (EO) or congressional legislation, may include travel bans, asset freezes, arms embargoes, capital restraints, foreign aid reductions, and trade restrictions.[4]

Export controls, another instrument of economic restriction, are "U.S. laws, regulations and policies governing the export and reexport of commodities, software, and technology (collectively "items") falling under the jurisdiction of the U.S. Department of the Treasury, Department of State, Department of Commerce, and Department of Energy."[5] Export controls are predominantly imposed to protect the transfer of dual-use goods, goods with both commercial civilian and military use, to designated state and non-state actors. The Department of Commerce's Bureau of Industry and Security (BIS) administers the Export Administrations Regulations (EAR) by classifying items on the Commerce Control List (CCL) and designating individuals or entities on the Entity List. In addition to BIS, the U.S. Department of State's Directorate of Defense Trade Controls (DDTC) administers the International Traffic in Arms Regulations (ITAR), and the U.S. Department of Treasury's Office of Foreign Assets Control (OFAC) enforces economic and sanctions programs.[6]

In addition to unilateral controls, the United States is a participant of multilateral export control regimes: the Wassenaar Arrangement regulates language surrounding the export of conventional arms and dual-use technologies; the Nuclear Suppliers Group (NSG) regulates the export of nuclear-related and dual-use materials, equipment and technology; the Australia Group regulates the export of chemical weapons, chemical production equipment technologies, and biological weapons; and, the Missile Technology Control Regime (MTCR) regulates the proliferation of missiles with weapons of mass destruction (WMD) capabilities.[7] In coordinating controls with allies, the United States is able to better prevent the unauthorized reexport of controlled items and limit circumvention, thereby increasing policy effectiveness and decreasing enforcement costs.[8]

This paper examines the circumstances under which states circumvent and innovate in the face of sustained technological denial. I examine three U.S. adversaries: China, Russia, and Iran. These adversaries have been respective targets of U.S. sustained technological denial in recent years and have also demonstrated some desire to develop domestic production lines for targeted technologies—semiconductors, liquefied natural gas (LNG) infrastructure, and unmanned

[3] Sarah Krulikowski, "Economic Sanctions: An Overview," United States International Trade Commission (March 2024), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.usitc.gov/sites/default/files/publications/332/executive_briefings/ebot_economic_sanctions_overview.pdf&ved=2ahUKEwirwJue0fKQAxWoljQIHSMQJuoQFnoECEkQAQ&usg=AOvVaw1DI46gPp4Brdio3tFNkl_i. Accessed November 14, 2025.
[4] "What Are Economic Sanctions," Council on Foreign Relations (June 24, 2024), https://www.cfr.org/backgrounder/what-are-economic-sanctions. Accessed November 13, 2025.
[5] "U.S. Export Controls," United States International Trade Administration, https://www.trade.gov/us-export-controls. Accessed November 14, 2025.
[6] "Overview of Export Controls," University of North Carolina - Charlotte, https://research.charlotte.edu/departments/office-research-protections-and-integrity-orpi/export-control/overview-export-controls/. Accessed November 14, 2025.
[7] Bureau of Industry and Security, "Multilateral Export Control Regimes," U.S. Department of Commerce, https://www.bis.gov/guidance-frequently-asked-questions/multilateral-export-control-regimes. Accessed November 13, 2025.
[8] "Export Controls—International Coordination: Issues for Congress," Congress.gov (September 8, 2023), https://www.congress.gov/crs-product/R47684. Accessed December 4, 2025.

autonomous vehicles (UAVs).[9] Within each case study, I outline restrictive U.S. policies, evaluate the efficacy of such policies in preventing state circumvention and innovation, and draw conclusions about the types of policies that are most effective in preventing sustained technological acquisition.

Because this research examines three distinct states, with unique state capacities, innovation models, and relationships within the global economy, the findings of this research are limited in context and complexity. Even so, this research offers insights on technologically capable and scientifically advanced adversaries that pursue the indigenous production, or circumvention, of targeted technologies.

[9] Chris Miller, *Chip War: The Fight for the World's Most Critical Technology* (New York, NY: Simon and Schuster, 2022); "First Russian-built ice-class LNG tanker to launch this year, Ifx reports," *Reuters* (June 25, 2025), https://www.reuters.com/business/energy/first-russian-built-ice-class-lng-tanker-launch-this-year-ifx-reports-2025-06-25/. Accessed September 9, 2025; Natalie Sedletska, Maksym Savchuk, Kyrylo Osyaniy and Carl Schreck, "How Western Tech In Iranian Drones Is Helping Russia Wage War on Ukraine," Radio Free Europe Radio Liberty (November 4, 2022), https://www.rferl.org/a/ukraine-russia-drones-iran-western-technology/32115733.html. Accessed September 9, 2025.

Case Study #1: Chinese Semiconductor Innovation

This case study examines the impact of U.S. economic policies on Chinese semiconductor acquisition. The tactics used by China to circumvent U.S. policies—smuggling, stockpiling, and utilizing shell companies—enable Chinese semiconductor acquisition. However, U.S. control over critical technological chokepoints limits China's advanced semiconductor production, rendering it so far unable to produce the most advanced artificial intelligence chips at-scale or to achieve independence from foreign industries.

Background

The case of China's semiconductor industry presents a valuable example of sustained technological denial. Since 2015, the United States has imposed a series of export controls, investment restrictions, and diplomatic pressures designed to limit China's access to advanced semiconductors, manufacturing equipment, and high-performance computing (HPC) capabilities. Washington justifies these measures as essential to protecting national security and maintaining a technological edge in emerging defense applications. These controls reflect a growing convergence in economic and security strategies, with the semiconductor domain emerging as a central battleground for technological competition.

For the past decade, the United States and China have competed for dominance in diplomatic, economic, technological, and military realms.[10] Because of China's integral role in the world economy and size, it is able to wield economic leverage over trade partners whose actions it perceives as undermining core Chinese interests, such as the "One China Principle," or territorial claims in the South and East China Seas.[11] China accounts for 35% of global gross production, having exported $3.1 trillion worldwide, and $442 billion to the United States in 2023, making it the number one exporter in the world.[12]

[10] Bilahari Kausikan, "Navigating the New Age of Great-Power Competition," Foreign Affairs (April 11, 2023), https://www.foreignaffairs.com/united-states/china-great-power-competition-russia-guide. Accessed September 9, 2025; "United States Strategic Approach to the People's Republica of China," Office of the President of the United States, 2020, Accessed September 10, 2025; Ryan Hass et al., "Advancing U.S.-China Coordination amid Strategic Competition: An Emerging Playbook," Center for Strategic and International Studies (January 15, 2025), https://www.csis.org/analysis/advancing-us-china-coordination-amid-strategic-competition-emerging-playbook. Accessed September 10, 2025.

[11] William Piekos, "How Beijing uses inducements as a tool of economic statecraft," Atlantic Council (March 24, 2025), https://www.atlanticcouncil.org/in-depth-research-reports/report/how-beijing-uses-inducements-as-a-tool-of-economic-statecraft/. Accessed November 26, 2025.

[12] "China (CHN) Exports, Imports, and Trade Partners," Observatory of Economic Complexity (September 17, 2025), https://oec.world/en/profile/country/chn. Accessed October 9, 2025; Gerard DiPippo and Benjamin Lenain, "testing the Self-Reliance: What the Trade War Reveals About China's Vulnerabilities and Power," RAND (June 10, 2025), https://www.rand.org/pubs/commentary/2025/06/testing-self-reliance-what-the-trade-war-reveals-about.html. Accessed September 14, 2025.

To replace the United States as global leader and strengthen Chinese sovereignty, Beijing has adopted an assertive posture towards the West whereby it attempts to dominate international institutions and shift the liberal international order towards one where China has a central role.[13] In turn, the United States revealed in its 2017 National Security Strategy a shift from deepening bilateral ties to officially declaring China a strategic competitor of the United States.[14]

History of Semiconductor Innovation

The semiconductor industry originated in the 1950s in California's Silicon Valley where engineers generated expertise in producing miniaturized technology to serve emerging needs in defense, space exploration, and consumer electronics sectors. The technology advanced rapidly. Moore's Law, a theory developed by Intel co-founder Gordon Moore in 1965, predicted that the number of transistors on an integrated circuit would continue to double every two years.[15] At the time, only the United States could foster such an exponential pace of innovation. With its eager domestic consumer market and a localized advantage in mass-production, the United States accounted for about 70% of the international semiconductor market in the 1970s. The burgeoning U.S. market increased demand for consumer electronics, thereby fueling innovation of the semiconductors required to operate them.[16]

As part of a broader strategy to integrate Japan into the U.S.-led economic orbit, U.S. firms licensed their chip designs to Japanese firms entering the market. Between 1970 and 1977, Japan's R&D spending grew by 24%, while the Japanese government (spearheaded by the Ministry of International Trade and Industry, MITI) funded a consortium of domestic technology research companies with $300 million.[17] In the following decade, South Korea and Taiwan imitated the Japan model by obtaining foreign technology and subsidizing domestic innovation.[18] Characterized by innovative industrial policies and close government-industry collaboration, the East-Asian approach proved essential to the firms' success.

[13] David C. Kang et al., "What Does China Want," *International Security 50,* no. 1 (2025): pp. 46-81. https://doi.org/10.1162/ISEC.a.5. Accessed September 15, 2025.
[14] "The National Security Strategy of the United States of America," Office of the President of the United States, 2018; Ashley J. Tellis, *Strategic Asia 2020: U.S.-China Competition for Global Influence* (Seattle, WA: National Bureau of Asian Research, 2020).
[15] "Understanding Moore's Law," Intel, April 9, 2025, https://newsroom.intel.com/tech101/understanding-moores-law. Accessed September 15, 2025.
[16]Richard Elkus Jr., "A Strategy for the United States to Regain its Position in Semiconductor Manufacturing," Center for Strategic and International Studies, February 13, 2024, https://www.csis.org/analysis/strategy-united-states-regain-its-position-semiconductor-manufacturing. Accessed September 16, 2025.
[17] Hideki Tomoshige, "Japan's Semiconductor Industrial Policy from the 1970s to Today," Center for Strategic and International Studies (September 19, 2022), https://www.csis.org/blogs/perspectives-innovation/japans-semiconductor-industrial-policy-1970s-today. Accessed November 26, 2025.
[18] Chris Miller, *Chip War: The Fight for the World's Most Critical Technology* (New York: Simon and Schuester, 2022).

U.S. firms could not keep up with the extraordinarily high prices of chip production plants, otherwise known as "fabs" (short for fabrication facilities) and offshored chip manufacturing to cheaper foundries in East Asia where there were lower costs, less restrictive regulatory policies, and favorable government incentives. U.S. firms became "fabless," focusing on chip design, while foundries in East Asia, such as Taiwan's Semiconductor Manufacturing Company (TSMC), specialized in mass-producing semiconductors.[19] The semiconductor industry has thus been described as a "fabless-foundry" industry in which some countries oversee the design of chips while others oversee production.

When Deng Xiaoping ascended to power and pledged to modernize China in 1976, he proclaimed semiconductor innovation a new priority of the People's Republic of China (PRC). However, the rapidly evolving pace of industry rendered emerging Chinese firms consistently 5 to 10 years behind their already-established American and East-Asian counterparts. By the 1980s, China was able to domestically produce DRAM (dynamic random-access memory) chips with the same storage capacity that U.S.-founded Intel had produced a decade earlier.[20] Bolstered by government subsidies, Chinese company Huawei entered the electronics industry in 1987, and SMIC (Semiconductor Manufacturing International Corporation) was founded in 2000 to compete with Taiwan-based TSMC. While Chinese firms slowly developed domestic capacity to produce simple chips and consumer electronics, and China earned its reputation as "electronic powerhouse," it continued to import its silicon from the United States, Japan, and Taiwan.[21]

Modern Semiconductors

Today's semiconductors are made up of natural elements, such as silicon, germanium, or gallium, and conduct electricity to process integrated circuits, also called microchips or chips. Chip size is measured in nanometers (nm) and generally, the smaller the chip, the more efficiently it operates. Chips are produced in 7 stages: design, wafer production, photolithography, etching, deposition, ion implantation, and assembly and packaging.[22] During the production process, a silicon wafer is shaped and smoothed down, covered in a chemical coating, and then, during the photolithography process, exposed to deep ultraviolet (DUV) or extreme ultraviolet (EUV) light. DUV and EUV reveal a pattern on which positive and negative ions are etched. Finally, the silicon wafer is diced into microscopic pieces.[23] Many firms specialize in individual steps of the production process, and few, if any, can produce a finished chip from start to finish.

[19] Chris Miller, *Chip War: The Fight for the World's Most Critical Technology* (New York: Simon and Schuester, 2022).
[20] Ibid.
[21] Ibid.
[22] Graham Ray, "What Are the Steps in Semiconductor Manufacturing?" Surfx Mycronic (December 31, 2024), https://www.surfxtechnologies.com/blog/what-are-the-steps-in-semiconductor-manufacturing/. Accessed September 22, 2025.
[23] Alison Li, "6 crucial steps in semiconductor manufacturing," ASML (October 4, 2023), https://www.asml.com/en/news/stories/2021/semiconductor-manufacturing-process-steps. Accessed September 18, 2025.

Chips are ubiquitous in almost every sector of the U.S. economy, and the defense industry is no exception. All major defense platforms rely on microchips, especially chips that use older, less advanced manufacturing processes. Such chips are called "legacy" or "mature" chips, and they operate most electrical devices, including automotives and consumer electronics and appliances.[24] Legacy chips are not at the cutting-edge of chip innovation, yet their reliability makes them invaluable to most military systems, including fighter jets, communications systems, and missile defense.

While the defense industry does not rely on advanced chips to operate fundamental military technology, advanced chips have the unique ability to operate high-performance computing (HPC), a technology that uses clusters of powerful processors in parallel to quickly process large amounts of data.[25] Bridging the gap between scientific theory and operational reality with highly sophisticated simulations, HPC provides the United States with a strategic military advantage. For example, Lawrence Livermore National Laboratory operates the world's fastest supercomputer, El Capitan, ensuring the U.S. nuclear deterrent by powering nuclear simulations, omitting the need for nuclear testing.[26] Beyond HPC, advanced chips drive the global artificial intelligence race, a domain with growing applications in defense systems.

There is an immense disparity between advanced chips and central processing units (CPUs), the general-purpose processor commonly found in consumer devices. An advanced AI chip, such as a graphics processing unit (GPU), field-programmable gate array (FPGA), or application-specific integrated circuit (ASIC), is more than 1000 times as efficient than a CPU.[27] According to a joint report by the National Security Agency and the National Nuclear Security Administration:

> "National security requires the best computing available and loss of leadership in HPC will severely compromise our national security. HPC plays a vital role in the design, development, or analysis of many—perhaps almost all—modern weapon systems and national security systems: e.g., nuclear weapons, cyber, ships, aircraft, encryption, missile decision, precision strike capability, and hypersonics."[28]

[24] Sujai Shivakumar and Charles Wessner, "Semiconductors and National Defense: What Are the Stakes?" Center for Strategic and International Studies (June 8, 2022), https://www.csis.org/analysis/semiconductors-and-national-defense-what-are-stakes. Accessed September 22, 2025.
[25] Stephanie Susnjara and Ian Smalley, "What is high-performance computing (HPC)?" IBM, *https://www.ibm.com/think/topics/hpc*. Accessed September 22, 2025.
[26] "Lawrence Livermore National Laboratory's El Capitan verified as world's fastest supercomputer," llnl.gov (November 17, 2025), https://www.llnl.gov/article/53596/el-capitan-retains-title-worlds-fastest-supercomputer-latest-top500. Accessed November 26, 2025. Accessed September 22, 2025.
[27] Sujai Shivakumar and Charles Wessner, "Semiconductors and National Defense: What Are the Stakes?" Center for Strategic and International Studies (June 8, 2022), https://www.csis.org/analysis/semiconductors-and-national-defense-what-are-stakes; Saif M. Kham and Alexander Mann, "AI Chips: What They Are and Why They Matter," Center for Security and Emerging Technology (April 2020). Accessed September 18, 2025.

The strategic value of advanced chips has prompted the United States to secure their stockpiles and related information from adversaries. Today, U.S. firms maintain their long-held status as champions of chip design, while Taiwan's TSMC reigns most competitive in chip fabrication. ASML, a Dutch company, holds a monopoly on the most advanced photolithography equipment.[29] The market also remains split internationally. Today, U.S. firms are responsible for 46% of global semiconductor sales, followed by South Korea (21%), Japan (9%), and Taiwan (8%).[30] Chinese indigenous production accounts for 7% of total semiconductor sales worldwide, though China lacks the capacity to produce state-of-the-art photolithography technology or advanced chips.[31] In the Semiconductor Manufacturing Equipment (SME) market, the United States and Japan produce 40.9% and 29.4% of global stock, as of 2024.[32] China, while not a major producer, has emerged as a large SME consumer market, and buys 45% of its SME stock from the United States, and 28% from Japan.[33] Most semiconductor fabrication facilities in the world rely on American-made SME and their onsite equipment providers in some capacity.

China's ecosystem of large government subsidies and government-industry coordination has made it the largest producer of legacy chips—chips using nodes at 28nm or above—and a top performer in DRAM chip production.[34] However, Chinese firms lack the capacity and know-how to produce advanced state-of-the-art processors and the equipment necessary to build them.[35] China has announced efforts to stimulate domestic chip innovation capabilities to limit dependency on foreign supply chains for advanced chips. China's "2014 National Guidelines for Development and Promotion of the IC [integrated circuit] Industry" called for $150 billion in investments to manage

[28] "U.S. Leadership in High Performance Computing (HPC)," *a Report from the NSA-DOE Technical Meeting on High Performance Computing* (December 1, 2016), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.nitrd.gov/nitrdgroups/images/b/b4/NSA_DOE_HPC_TechMeetingReport.pdf&ved=2ahUKEwjyrYW8qZ2RAxWHyOYEHcKwBsYQFnoECBcQAQ&usg=AOvVaw1Q05b1zUiZErzrkOBTNulF, p. 3. Accessed September 19, 2025.
[29] Stephen Ezell, "How Innovative is China in Semiconductors?" *Information Technology & Innovation Foundation* (August 19, 2024), https://itif.org/publications/2024/08/19/how-innovative-is-china-in-semiconductors/. Accessed September 20, 2025.
[30] Ibid.
[31] Semiconductor Industry Association, "Global Semiconductor Sales Increase 21.7% Year-to-Year in August," Semiconductor Industry Association (October 3, 2025), https://www.semiconductors.org/global-semiconductor-sales-increase-21-7-year-to-year-in-august/. Accessed October 9, 2025.
[32] Ibid.
[33] Akhil Thadani and Gregory C. Allen, "Mapping the Semiconductor Supply Chain: The Critical Role of the Indo-Pacific Region," Center for Strategic and International Studies (May 30, 2023), https://www.csis.org/analysis/mapping-semiconductor-supply-chain-critical-role-indo-pacific-region. Accessed September 22, 2025.
[34] Stephen Ezell, "How Innovative is China in Semiconductors?" Information Technology & Innovation Foundation (August 19, 2024), https://itif.org/publications/2024/08/19/how-innovative-is-china-in-semiconductors/. Accessed September 20, 2025.
[35] Ibid.

the entire life cycle of semiconductors.[36] Likewise, China's "Made in China 2025" policy aims to reduce reliance on foreign technology and rapidly modernize China's industrial base.[37]

U.S. Policies Restricting Access

The below executive orders constitute three pillars of U.S. strategy as of 2025: restricting Chinese access to U.S.-made AI and supercomputing materials, constraining China's domestic capability to produce advanced chips, and fostering American domestic production capacity.[38] Former National Security Advisor Jake Sullivan described the policy regime as "small yard, high fence," meaning that only advanced AI chips are restricted by export controls, while civilian chips are not restricted.[39]

Table 1: US Export Controls Targeting Chinese Semiconductor Acquisition

U.S. Policy/Instrument	Year Enacted	Target
Department of Commerce's BIS prohibits Intel from selling Xeon chips to Chinese military research centers[40]	April 2015	Chinese supercomputing programs engaged in nuclear research
BIS prohibits firms from exporting materials to Chinese telecommunications company, ZTE[41]	April 2018 (until July 2018)	ZTE, after violating American sanctions on Iran and North Korea
BIS adds Huawei Technologies and 152 affiliates to the Entity List[42]	May 2019	Huawei, its 152 non-U.S. affiliates
BIS extends the Foreign Direct Product Rule (FDPR) to Huawei[43]	May 2020	Huawei, its affiliates, and foreign firms using U.S. technology

[36] Sujai Shivakumar, Charles Wessner, and Thomas Howell, "The Limits of Chip Export Controls in Meeting the China Challenge," Center for Strategic and International Studies (April 14, 2025), https://www.csis.org/analysis/limits-chip-export-controls-meeting-china-challenge Accessed September 10, 2025; Stephen Ezell, "How Innovative is China in Semiconductors?" Information Technology & Innovative Foundation (August 19, 2024), https://itif.org/publications/2024/08/19/how-innovative-is-china-in-semiconductors/. Accessed September 20, 2025.
[37] Kaiser Kuo, "Made in China 2.0: The future of global manufacturing?" World Economic Forum (June 26, 2025), https://www.weforum.org/stories/2025/06/how-china-is-reinventing-the-future-of-global-manufacturing/. Accessed September 25, 2025.
[40] "US nuclear fears block Intel China supercomputer update," BBC (April 10, 2015), https://www.bbc.com/news/technology-32247532. Accessed September 26, 2025.
[41] Meagan Tobin, "How Washington Has Tried to Control China's Tech," New York Times (June 12, 2025), https://www.nytimes.com/2025/06/12/business/washington-china-export-controls-tech-huawei.html. Accessed September 18, 2025,
[42] Industry and Security Bureau, "Addition of Entities to the Entity List," Federal Register, https://www.federalregister.gov/documents/2019/05/21/2019-10616/addition-of-entities-to-the-entity-list. Accessed November 26, 2025.

BIS prohibits U.S. firms from exporting materials to SMIC[44]	September 2020	SMIC and U.S. firms
BIS announces export restrictions on AI and supercomputing chips[45]	September 2022	All Chinese individuals/entities
BIS announced broadened restrictions to include semiconductor production chokepoints and applied the FDPR to additional entities[46]	October 2022	All Chinese individuals/entities and foreign firms using U.S. technology
The United States pressures ASML to restrict trade with China[47]	January 2024	ASML, All Chinese individuals/entities
BIS announced broad restrictions on high-bandwidth memory (HBM), SME, and allied firms; BIS introduces new license exceptions[48]	December 2024	All Chinese individuals/entities and allied foreign individuals/entities
BIS announced updating restrictions on advanced semiconductors and designated additional Chinese/Singaporean entities to the Entity List[49]	January 2025	Shell companies and third-party foundries

Sources: For links to the source materials, please see in-text footnotes. Data was collected from BBC, New York Times, U.S. Department of Commerce Bureau of Industry and Security, Federal Register, Congress.gov, and CSIS.
Note: The above table represents the most relevant economic restrictions targeting China's semiconductor sector. For a more exhaustive list of policies, see: Caroline Wesson, "Innovating Around Export Controls Under Technology Competition: The Case of China and Advanced Semiconductors," in Kimberly Peh and Michael Albertson, ed., *In Search*

[41] Meagan Tobin, "How Washington Has Tried to Control China's Tech," New York Times (June 12, 2025), https://www.nytimes.com/2025/06/12/business/washington-china-export-controls-tech-huawei.html. Accessed September 18, 2025,
[42] Industry and Security Bureau, "Addition of Entities to the Entity List," Federal Register, https://www.federalregister.gov/documents/2019/05/21/2019-10616/addition-of-entities-to-the-entity-list. Accessed November 26, 2025.
[43] "Export Administration Regulations: Amendments to General Prohibition Three (Foreign-Produced Direct Product Rule) and the Entity List," Federal Register (May 19, 2020), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.federalregister.gov/documents/2020/05/19/2020-10856/export-administration-regulations-amendments-to-general-prohibition-three-foreign-produced-direct&ved=2ahUKEwiPn4HSqp2RAxX2HzQIHQVIJZIQFnoECBgQAQ&usg=AOvVaw3NGpAoQPQu8BvaTcVCcpvb. Accessed November 26, 2025.
[44] "U.S. Export Controls and China: Advanced Semiconductors," Congress.gov, https://www.congress.gov/crs-product/R48642. Accessed November 26, 2025.
[45] Ibid.
[46] Gregory C. Allen, "Choking Off China's Access to the Future of AI," Center for Strategic and International Studies (October 11, 2022), https://www.csis.org/analysis/choking-chinas-access-future-ai. Accessed September 16, 2025.
[47] Sujai Shivakumar, Charles Wessner, and Thomas Howell, "Balancing the Ledger: Export Controls on U.S. Chip Technology to China," Center for Strategic and International Studies (February 21, 2024), https://www.csis.org/analysis/balancing-ledger-export-controls-us-chip-technology-china. Accessed November 26, 2025.
[48] "Commerce Strengthens Export Controls to Restrict China's Capability to Produce Advanced Semiconductors for Military Applications," Bureau of Industry & Security (December 2, 2024), https://www.bis.gov/press-release/commerce-strengthens-export-controls-restrict-chinas-capability-produce-advanced-semiconductors-military. Accessed November 26, 2025.
[49] "Commerce Strengthens Restrictions on Advanced Computing Semiconductors to Enhance Foundry Due Diligence and Prevent Diversion to PRC," Bureau of Industry & Security, (January 15, 2025), https://www.bis.gov/press-release/commerce-strengthens-restrictions-advanced-computing-semiconductors-enhance-foundry-due-diligence-prevent. Accessed November 26, 2025.

of Strategic Advantage: Understanding The Landscape of Technology Competition (Livermore, CA: Center for Global Security Research, November 2025), pp. 51-73.

The Biden Administration's 2022 export controls framed the policies as a national security imperative:

> "With this rule, BIS seeks to protect U.S. national security and foreign policy interests by restricting the PRC's access to advanced computing for its military modernization, including nuclear weapons development, facilitation of advanced intelligence collection and analysis, and for surveillance. BIS intends to impose controls on items subject to the EAR and U.S. person activities to limit the PRC's ability to obtain advanced computing chips or further develop AI and "supercomputer" capabilities for uses that are contrary to U.S. national security and foreign policy interests."[50]

The United States also coordinated a multilateral approach to trade controls: it pressured ASML, the Dutch firm with the most advanced photolithography equipment, to halt shipments of its advanced DUV equipment to China, and contributed to multilateral frameworks, such as the Wassenaar Arrangement, to ensure broad enforcement of export controls with allies.[51]

Were U.S. policies effective?

U.S. export controls have achieved mixed results. Some restrictions have significantly constrained China's access to advanced chips, while others have proven less effective due to loopholes in enforcement, inconsistent multilateral coordination, and the narrow scope of certain regulations. These gaps enable Chinese firms to exploit workarounds such as stockpiling, shell companies, and smuggling networks. The table below outlines whether key U.S. restrictions were effective in achieving their intended impact. Effectiveness is assessed based on how these policies, together with prior measures, limit the sustained technological acquisition of semiconductors and related goods.

Table 2: Effectiveness of U.S. Restrictions on China

[50] Department of Commerce Bureau of Industry and Security, "Implementation of Additional Export Controls: Certain Advanced Computing and Semiconductor Manufacturing Items; Supercomputer and Semiconductor End Use; Entity List Modification," Federal Register (October 13, 2022), https://www.federalregister.gov/documents/2022/10/13/2022-21658/implementation-of-additional-export-controls-certain-advanced-computing-and-semiconductor. Accessed September 22, 2025.

[51] Rebecca Arcesati, "To stand up to US pressure, Europe needs better intelligence on China's innovation system, Mercator Institute for China Studies (June 6, 2024), https://merics.org/en/comment/stand-us-pressure-europe-needs-better-intelligence-chinas-innovation-system. Accessed September 23, 2025.

U.S. Policy/Instrument	Year Enacted	Intended Impact Achieved?	Explanation of Impact
Department of Commerce's BIS prohibits Intel from selling Xeon chips to Chinese military research centers[52]	April 2015	Not Achieved	Close integration of commercial and military sectors enabled continued access[53]
BIS prohibits firms from exporting materials to Chinese telecommunications company, ZTE[54]	April 2018 (until July 2018)	Significantly Achieved	Export ban lifted only after ZTE paid a $1 billion fine[55]
BIS adds Huawei Technologies and 152 affiliates to the Entity List[56]	May 2019	Partially Achieved	Blocked from direct purchases, but circumvented restrictions via intermediates[57]
BIS extends the Foreign Direct Product Rule (FDPR) to Huawei[58]	May 2020	Significantly Achieved	Blocked access to end products and production inputs[59]

[52] "US nuclear fears block Intel China supercomputer update," BBC (April 10, 2015), https://www.bbc.com/news/technology-32247532. Accessed September 26, 2025.
[53] [53] Gregory C. Allen, "Choking Off China's Access to the Future of AI," Center for Strategic and International Studies (October 11, 2022), https://www.csis.org/analysis/choking-chinas-access-future-ai. Accessed September 16, 2025.
[54] Meagan Tobin, "How Washington Has Tried to Control China's Tech," New York Times (June 12, 2025), https://www.nytimes.com/2025/06/12/business/washington-china-export-controls-tech-huawei.html. Accessed September 18, 2025,
[55] Karen Freifeld and Sarah N. Lynch, "Exclusive: China's ZTE may pay over $1 billion to the US over foreign bribery allegations, sources say," Reuters (December 11, 2025), https://www.reuters.com/sustainability/society-equity/chinas-zte-may-pay-more-than-1-billion-us-over-foreign-bribery-allegations-2025-12-11/. Accessed December 11, 2025.
[56] Industry and Security Bureau, "Addition of Entities to the Entity List," Federal Register, https://www.federalregister.gov/documents/2019/05/21/2019-10616/addition-of-entities-to-the-entity-list. Accessed November 26, 2025.
[57] Commerce Tightens Huawei Restrictions; Aims to Close Loopholes," Wiley (August 18, 2020), https://www.wiley.law/alert-Commerce-Tightens-Huawei-Restrictions-Aims-to-Close-Loopholes. Accessed December 11, 2025.
[58] "Export Administration Regulations: Amendments to General Prohibition Three (Foreign-Produced Direct Product Rule) and the Entity List," Federal Register (May 19, 2020), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.federalregister.gov/documents/2020/05/19/2020-10856/export-administration-regulations-amendments-to-general-prohibition-three-foreign-produced-direct&ved=2ahUKEwiPn4HSqp2RAxX2HzQIHQVIJZIQFnoECBgQAQ&usg=AOvVaw3NGpAoQPQu8BvaTcVCcpvb. Accessed November 26, 2025.
[59] Annie Froehlich, "Foreign Direct Product Rule: Is Russia the next Huawei?" Atlantic Council (February 3, 2022), https://www.atlanticcouncil.org/blogs/econographics/foreign-direct-product-rule-is-russia-the-next-huawei/. Accessed December 11.

BIS prohibits U.S. firms from exporting materials to SMIC[60]	September 2020	Partially Achieved	Blocked from direct purchases but accessed goods via intermediaries[61]
BIS announces export restrictions on AI and supercomputing chips[62]	September 2022	Not Achieved	Targeted the sale of chips only; intermediate goods and foreign firms using U.S. tools were not targeted[63]
BIS announced broadened restrictions to include semiconductor production chokepoints and applied the FDPR to additional entities[64]	October 2022	Significantly Achieved	Restricted from buying end-product, intermediary materials, restricted firms using U.S. goods selling to restricted entities[65]
The United States pressures ASML to restrict trade with China[66]	January 2024	Significantly Achieved	ASML halted exports of advanced photolithography equipment to China[67]
BIS announced broad restrictions on high-bandwidth memory (HBM) and SME; BIS introduces new license exceptions[68]	December 2024	Significantly Achieved	Closed loopholes and expanded enforcement scope[69]

[60] "U.S. Export Controls and China: Advanced Semiconductors," Congress.gov, https://www.congress.gov/crs-product/R48642. Accessed November 26, 2025.
[61] Sujai Shivakumar et al., "A Seismic Shift: The New U.S. Semiconductor Export Controls and the Implications for U.S. Firms, Allies, and the Innovation Ecosystem," Center for Strategic and International Studies (November 14, 2022), https://www.csis.org/analysis/seismic-shift-new-us-semiconductor-export-controls-and-implications-us-firms-allies-and. Accessed December 12, 2025.
[62] Ibid.
[63] William Alan Reinsch et al., "Insight into the U.S. Semiconductor Export Controls Update," Center for Strategic and International Studies (October 20, 2023), https://www.csis.org/analysis/insight-us-semiconductor-export-controls-update. Accessed December 12, 2025.
[64] Gregory C. Allen, "Choking Off China's Access to the Future of AI," Center for Strategic and International Studies (October 11, 2022), https://www.csis.org/analysis/choking-chinas-access-future-ai. Accessed September 16, 2025.
[65] Ibid.
[66] Sujai Shivakumar, Charles Wessner, and Thomas Howell, "Balancing the Ledger: Export Controls on U.S. Chip Technology to China," Center for Strategic and International Studies (February 21, 2024), https://www.csis.org/analysis/balancing-ledger-export-controls-us-chip-technology-china. Accessed November 26, 2025.
[67] Debby Wu, "China Lags in Chip Lithography Influential DC Think Tank Says," Bloomberg (July 14, 2025), https://www.bloomberg.com/news/articles/2025-07-14/china-lags-in-chip-lithography-influential-dc-think-tank-says. Accessed September 20, 2025.
[68] "Commerce Strengthens Export Controls to Restrict China's Capability to Produce Advanced Semiconductors for Military Applications," Bureau of Industry & Security (December 2, 2024), https://www.bis.gov/press-release/commerce-strengthens-export-controls-restrict-chinas-capability-produce-advanced-semiconductors-military. Accessed November 26, 2025.
[69] Gregory C. Allen, "Understanding the Biden Administration's Updated Export Controls," Center for Strategic and International Studies (December 11, 2024), https://www.csis.org/analysis/understanding-biden-administrations-updated-export-controls. Accessed December 12, 2025.

BIS announced updating restrictions on advanced semiconductors and designated additional Chinese/Singaporean entities to the Entity List; implemented Foundry Rule[70]	January 2025	Significantly Achieved	Closed loopholes and expanded enforcement scope[71]

The most effective policies achieved their impact because they successfully isolated processes of the semiconductor supply chain and focused on specific areas with significant U.S. leverage.[72] For example, the Biden Administration's October 2022 export controls indicated a policy shift to an approach that leveraged U.S. dominance in technology chokepoints to restrict Chinese access. A complement to the September 2022 export controls that restricted the sale of advanced chips, the October policies focused on retaining control of critical chokepoints in the semiconductor supply chain, with particular focus on AI chip designs, electronic design automation software, SME, and equipment components.[73] The policy restricted Chinese firms from accessing any U.S. technologies relevant to semiconductor production. Similarly, in 2024, the United States imposed the Foundry Rule, a rule that further restricted foundries relying on U.S.-made SME to working only with vetted firms. During the same year, the United States increased pressure on the Netherlands to restrict ASML from exporting its photolithography equipment to Chinese firms.[74]

Some policies were initially susceptible to circumvention. Before the May 2020 Foreign Direct Product Rule (FDPR) was imposed, Huawei bypassed restrictions by using intermediary firms or shell companies when interacting with foundries. From Taiwan's TSMC, Huawei received 2 million 7nm computer chiplets for its Ascend 910 AI processors between 2019 and 2020.[75] To protect foundries from manufacturing for shell companies, in 2020 the United States imposed the FDPR on Huawei, restricting Huawei technologies and its affiliates from using services by foundries using U.S.-made SME. The rule effectively restricted Huawei's access to TSMC manufacturing services, and Huawei's second-generation Ascend 910B processor, released in 2022, uses chips produced

[70] "Commerce Strengthens Restrictions on Advanced Computing Semiconductors to Enhance Foundry Due Diligence and Prevent Diversion to PRC," Bureau of Industry & Security, (January 15, 2025), https://www.bis.gov/press-release/commerce-strengthens-restrictions-advanced-computing-semiconductors-enhance-foundry-due-diligence-prevent. Accessed November 26, 2025.
[71] "New U.S. Export Controls on Advanced Computing Items and Artificial Intelligence Model Weights: Seven Key Takeaways," Sidley (January 21, 2025), https://datamatters.sidley.com/2025/01/21/new-u-s-export-controls-on-advanced-computing-items-and-artificial-intelligence-model-weights-seven-key-takeaways/. Accessed December 12, 2025.
[72] Gregory C. Allen, "Understanding the Biden Administration's Updated Export Controls," Center for Strategic and International Studies (December 11, 2024), https://www.csis.org/analysis/understanding-biden-administrations-updated-export-controls. Accessed December 12, 2025.
[73] Ibid.
[74] Sujai Shivakumar, Charles Wessner, and Thomas Howell, "Balancing the Ledger: Export Controls on U.S. Chip Technology to China," Center for Strategic and International Studies (February 21, 2024), https://www.csis.org/analysis/balancing-ledger-export-controls-us-chip-technology-china. Accessed November 26, 2025.
[75] Sujai Shivakumar, Charles Wessner, and Thomas Howell, "The Limits of Chip Export Controls in Meeting the China Challenge," Center for Strategic and International Studies (April 14, 2025), https://www.csis.org/analysis/limits-chip-export-controls-meeting-china-challenge Accessed September 10, 2025

by Chinese foundries.[76] The Ascend 910B processor uses fewer active AI cores than its predecessor, revealing marginal improvements, however, without access to U.S. SME the processors failed to maintain pace with U.S. industry counterparts.[77]

Similarly, in anticipation of U.S. export controls, Chinese firms moved to legally purchase and store large quantities of U.S.-made chips. In 2022, the United States placed restrictions on U.S.-based Nvidia's most advanced AI chips, including the A100 and H100. To maintain their Chinese market share, Nvidia manufactured and sold to China the A800 and H800 chips, chips just below the regulation threshold of the October 2022 export controls.[78] While technically legal, the sale violated the spirit of existing export controls by selling chips that performed similar functions as restricted chips. Before the Biden Administration moved to restrict the sale of the lower-threshold chips in October 2023, Chinese firms stockpiled them, with Nvidia disclosing the sale of $9 billion in chips to China between 2022 and 2023.[79] Further, preempting export controls restricting Nvidia's H20 chips, Chinese firms ByteDance, Alibaba, and Tencent spent $16 billion in stockpiling units.[80]

The earliest export control policies introduced by the Obama and Trump administrations were fundamentally challenging to enforce. Policies that did not target all Chinese entities and all segments of the semiconductor supply chain allowed Chinese firms to circumvent U.S. restrictions through front companies. The 2015 U.S. ban on Intel's sale of advanced Xeon chips to Chinese defense firms intended to curb nuclear research at institutions like China's National University of Defense Technology (NUDT) but did not restrict commercial industries.[81] The ban was circumvented when Chinese shell companies purchased the restricted chips and transferred them to NUDT. China's civil-military fusion enables such collaboration, and NUDT's Tianhe-2 supercomputer still uses Intel's high-end Xeon processors.[82]

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[76] [76] Jacob Feldgoise and Hanna Dohmen, "Pushing the Limits: Huawei's AI Chip Tests U.S. Export Controls," Center for Security and Emerging Technology (June 17, 2024), https://cset.georgetown.edu/publication/pushing-the-limits-huaweis-ai-chip-tests-u-s-export-controls/. Accessed September 16, 2025.

[77] Ibid.

[78] "U.S. Export Controls and China: Advanced Semiconductors," Congress.gov, https://www.congress.gov/crs-product/R48642. Accessed November 26, 2025.

[79] [79] Ana Swanson and Meaghan Tobin, "Do China's A.I. Advances Mean U.S. Technology Controls Have Failed?"; Congressional Testimony by Gregory C. Allen, "DeepSeek: A Deep Dive," Center for Strategic and International Studies, (April 8, 2025), https://www.csis.org/analysis/deepseek-deep-dive. Accessed September 22, 2025.

[80] Kyle Chan and Ray Wang, "Leashing Chinese AI Needs Smart Chip Controls," RAND (August 4, 2025), https://www.rand.org/pubs/commentary/2025/08/leashing-chinese-ai-needs-smart-chip-controls.html. Accessed September 18, 2025.

[81] Gregory C. Allen, "Choking off China's Access to the Future of AI," Center for Strategic and International Studies (October 11, 2022), https://www.csis.org/analysis/choking-chinas-access-future-ai. Accessed September 14, 2025.

[82] "US nuclear fears block Intel China supercomputer update," BBC (April 10, 2015), https://www.bbc.com/news/technology-32247532; "TIANHE-2A -TH – IVB-FEP CLUSTER, INTEL XEON E5-2692V2 12C 2.2GHZ, THE EXPRESS-2, MATRIX-2000," Top500 The List, https://www.top500.org/system/177999/. Accessed September 27, 2025; "The Chinese Communist Party's Military-Civil Fusion Policy," U.S. Department of State, https://2017-2021.state.gov/military-civil-fusion/. Accessed September 27, 2025.

Each of the above policies remain somewhat susceptible to smuggling. Because U.S. firms do not sell directly to consumers, and instead sell to distributors who, in turn, sell to smaller firms, it is difficult to track sales. By diverting sales, obfuscating company details, and using fraudulent shipping labels, smuggling networks illicitly sell billions of dollars in advanced chips. In one instance, smuggling networks facilitated the transfer of 2,400 Nvidia H100s to a PRC customer in 2024.[83] In 2025, Singaporean authorities arrested a group accused of smuggling Nvidia chips via fraudulent shell company, "Luxuriate Your Life," which illegally exported millions of dollars in Nvidia chips.[84] In some cases, Chinese entities access advanced chip capabilities via Cloud Service Providers (CSPs). Some estimates reveal that smuggled chips comprise around 6% of Chinese inference compute capacity.[85]

More enduring than the smuggling issue, there are indications that export controls are having an acceleratory effect on Chinese indigenous innovation.[86] In the face of restrictive U.S. policies, the Chinese government has adopted a series of policies which aim to "innovate around" controls and develop domestic production capacity: setting industry standards, providing hefty subsidies to firms, investing in education for related fields, connecting academia, research, and government organizations, and articulating a national strategy for innovation.[87]

Currently, Chinese firms are producing 7nm chips, while state-of-the-art advanced semiconductors operate at the 2nm and 3nm level.[88] Experts assess that as of 2024, Chinese firms are only five years away from state-of-the-art manufacturing, revealing steady progress in Chinese industry capabilities.[89] However, the gap is wider in some subsectors, such as SME manufacturing

[83] Erich Grunewald and Tim Fist, "Countering AI Chip Smuggling Has Become a National Security Priority," Center for a New American Security (June 11, 2025), https://www.cnas.org/publications/reports/countering-ai-chip-smuggling-has-become-a-national-security-priority. Accessed September 16, 2025.
[84] Xinghui Kok, "Singapore charges three with fraud that media link to Nvidia chips," Reuters (February 27, 2025), https://www.reuters.com/technology/singapore-charges-three-with-fraud-that-media-link-nvidia-chips-2025-02-28/. Accessed September 16, 2025; Kitty Wheeler, "The Smuggling of Nvidia's Chips Into China: Explained," AI Magazine (August 6, 2025), https://aimagazine.com/news/arrests-made-as-millions-of-nvidia-chips-smuggled-into-china. Accessed September 16, 2025.
[85] Erich Grunewald and Tim Fist, "Countering AI Chip Smuggling Has Become a National Security Priority," Center for a New American Security (June 11, 2025), https://www.cnas.org/publications/reports/countering-ai-chip-smuggling-has-become-a-national-security-priority. Accessed September 16, 2025.
[86] Hannah Dohmen, Jacob Feldgoise, and Charles Kupchan, "The Limits of the China Chip Ban," Foreign Affairs (July 24, 2024), https://www.foreignaffairs.com/china/limits-china-chip-ban. Accessed September 22, 2025.
[87] Caroline Wesson, "Innovating Around Export Controls Under Technology Competition: The Case of China and Advanced Semiconductors," in Kimberly Peh and Michael Albertson, ed., *In Search of Strategic Advantage: Understanding The Landscape of Technology Competition* (Livermore, CA: Center for Global Security Research, November 2025), pp. 51-73.
[88] "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 September 22, 2025.
[89] Stephen Ezell, "How Innovative Is China in Semiconductors," Information Technology & Innovation Foundation, August 19, 2024, https://itif.org/publications/2024/08/19/how-innovative-is-china-in-semiconductors/. Accessed September 20, 2025.

and photolithography.[90] China's best fabrication facilities still rely on restricted equipment, and Chinese firms are incapable of producing the most advanced chips without such SME. While Chinese firms can produce some 7nm chips, Huawei and SMIC have struggled to reliably mass-produce 7nm chips or smaller. Georgetown's Center for Strategic and Emerging Technology describes the impact: "Even in the i-line lithography tool segment—tools for legacy chip fabrication—China has only maintained a modest 4% of market share. Lithography remains the critical chokepoint where foreign incumbents maintain a formidable lead."[91] The most prescient explanation for this is the lack of access to EUV machines from the Netherland's ASML and semiconductor manufacturing equipment from U.S. firms.

Lessons Learned from Chinese Semiconductor Innovation

U.S. policies have proven most effective when:

- pursued in coordination with allies
- isolating processes of the semiconductor supply chain where the United States and its allies have significant leverage (for example photolithography equipment and SME)
- targeting inputs, intermediary goods, and machinery used to produce final goods
- targeting technologies that depend on large-scale, sustained access to confer high-performance capabilities

U.S. policies have been less effective when:

- failing to effectively coordinate with industry counterparts
- targeting technologies and industries where the ultimate end-user is difficult to identify

U.S. policies have proven most effective when pursued in coordination with allies and industry partners. The highly fragmented and rapidly evolving nature of the semiconductor supply chain creates critical chokepoints. The United States and its allies maintain dominance in SME, photolithography, and advanced chip production, and leverage such influence to restrict Chinese access to these technological chokepoints. Policies that restrict Chinese access to chokepoints succeeded because of the supply chain's unique composition and the specific nature of

[90] Elizabeth Brotherton-Bunch, "China is Five Years Behind Global Competitors in Chip Innovation, But is 'Rapidly Closing the Gap'," Alliance for American Manufacturing (August 20, 2024), https://www.americanmanufacturing.org/blog/china-is-five-years-behind-global-competitors-in-chip-innovation-but-is-rapidly-closing-the-gap/. Accessed September 23, 2025.

[91] Jacob Feldgoise and Hanna Dohmen, "Inside Beijing's Chipmaking Offensive," Center for Security and Emerging Technology (July 14, 2025), https://cset.georgetown.edu/article/inside-beijings-chipmaking-offensive/. Accessed September 20, 2025; Debby Wu, "China Lags in Chip Lithography Influential DC Think Tank Says," Bloomberg (July 14, 2025), https://www.bloomberg.com/news/articles/2025-07-14/china-lags-in-chip-lithography-influential-dc-think-tank-says. Accessed September 20, 2025.

semiconductor-related goods. Because these policies are difficult to circumvent, China is unable to obtain high-end semiconductors in a meaningful or sustained way.[92]

On the other hand, the relationship with industry has proven less effective. Because export controls cut deeply into U.S. firms' market share in the short-term, some organizations hold an unfavorable view of those policies and at times seek to circumvent restrictions in exchange for preserving profit, as is the case with Nvidia, who produced specialized chips specifically for its Chinese market and maintains relaxed end-use verification standards. One article writes, "some distributors have been lax in reviewing buyers' information, allowing Chinese chip brokers to purchase restricted chips through shell companies that mask the true buyer's Chinese identity."[93] Some experts assess that export controls run counter to domestic firms' interests, as they spur foreign technological innovation, resulting in decreased revenues, profitability, and stock market capitalization for U.S. firms. On the other hand, some analysts argue that controls are necessary to prevent long-term competition from foreign competitors.[94]

To date, China's circumvention methods have been unable to secure consistent, large-scale access to AI chips, leaving it without the supply needed to achieve its goal of nationwide technological modernization and semiconductor self-sufficiency.[95] However, through smuggling, stockpiling, and shell-companies, Chinese firms have gathered enough advanced chips to effectively train AI models and power mid-range defense systems.[96] According to one report by the Center for a New American Security, Chinese AI chip smuggling may account for approximately 140,000 chips total.[97] For reference, a model like OpenAI's ChatGPT-4 requires training by ~30,000 Nvidia A100 chips.[98]

State capital has made a significant impact on the overall number of chip design firms in China; however, it has not guaranteed the success of such firms. In 2024, over 14,000 Chinese chip firms

[92] Sujai Shivakumar, Charles Wessner, and Thomas Howell, "The Limits of Chip Export Controls in Meeting the China Challenge," Center for Strategic and International Studies (April 14, 2025), https://www.csis.org/analysis/limits-chip-export-controls-meeting-china-challenge. Accessed September 10, 2025.
[93] Qianer Liu, "Nvidia AI Chip Smuggling to China Becomes an Industry," Information (August 12, 2024), https://www.theinformation.com/articles/nvidia-ai-chip-smuggling-to-china-becomes-an-industry. Accessed September 14, 2025.
[94] Marco Machiavelli et al., "Back & Forth 5: Do Export Controls Erode the United States' Lead – Or Protect It?" Center for Strategic and International Studies (August 13, 2025), https://www.csis.org/analysis/back-forth-5-do-export-controls-erode-united-states-lead-or-protect-it. Accessed September 16, 2025.
[95] Sujai Shivakumar et al., "The Limits of Chip Export Controls in Meeting the China Challenge," Center for Strategic and International Studies (August 14, 2025), https://www.csis.org/analysis/limits-chip-export-controls-meeting-china-challenge. Accessed September 10, 2025; Gregory C. Allen, "Choking off China's Access to the Future of AI," Center for Strategic and International Studies (October 11, 2022), https://www.csis.org/analysis/choking-chinas-access-future-ai. Accessed September 10, 2025.
[96] Erich Grunewald and Tim Fist, "Countering AI Chip Smuggling Has Become a National Security Priority," Center for a New American Security (June 11, 2025), https://www.cnas.org/publications/reports/countering-ai-chip-smuggling-has-become-a-national-security-priority. Accessed October 9, 2025.
[97] Ibid.
[98] Ibid.

shut down.[99] China' approach to science and technology innovation relies on extraordinary volumes of state-directed capital, a necessary but insufficient means to achieving progress.

The reality of a global economy means that all export control regimes are susceptible to some workarounds. The United States and its allies have created the most comprehensive and adaptive set of semiconductor restrictions to date, policies that continue to evolve in response to creative Chinese circumvention. Still, U.S. policy remains effective in delaying Chinese innovation and closing some pathways for circumvention, though it has not stopped innovation and circumvention altogether. This strategic delay preserves U.S. firms' lead in technological innovation, buying critical time for the United States to strengthen domestic capacity, deepen allied cooperation, and safeguard long-term technological dominance.

[99] Hideki Tomoshige, "Innovation Lightbulb: Innovation Competition in Chip Design Between the U.S. and China," Center for Strategic and International Studies (February 21, 2025), https://www.csis.org/analysis/innovation-lightbulb-innovation-competition-chip-design-between-us-and-china. Accessed October 10, 2025; "Over 14,000 Chinese Chip Firms Reportedly Shut down in 2024 amid Accelerating Reshuffle," TrendForce (December 12, 2024), https://www.trendforce.com/news/2024/12/24/news-over-14000-chinese-chip-firms-reportedly-shut-down-in-2024-amid-accelerating-reshuffle/. Access October 10, 2025.

Case Study #2: Russian LNG Vessel Innovation

This case study examines the impact of U.S. economic policies on Russian liquefied natural gas (LNG) infrastructure acquisition and innovation. The tactics used by Russia to circumvent U.S. policies – third party intermediaries and LNG shadow vessels – enable limited Russian LNG infrastructure acquisition. However, U.S. control over critical technological chokepoints and maritime services both limits and delays Russian LNG liquefaction and transportation.

Background

The United States first imposed targeted economic restrictions on Russia's LNG sector in the months following Moscow's 2014 annexation of Crimea. These policies were steadily expanded until Russia's full-scale invasion of Ukraine in 2022 when Washington intensified this pressure. Since then, U.S. strategy has sought to cut Russian export revenue, constrain Russia's military capacity, and impose pain on the Russian economy.[100] In service of these goals, the United States implemented export controls and sanctions to exploit Russian reliance on Western-made components critical to the liquefaction and transportation of LNG.

Russia is among the world's largest gas exporters, and fuel and energy products account for 63% of its total exports as of 2023.[101] Russia has traditionally exported its natural gas to Europe through pipeline infrastructure. However, following Russia's 2022 invasion, Russia cut its gas exports to Europe in retaliation for sanctions Europe imposed on Russia in support of Ukraine, thus deepening Russia's efforts to expand gas exports to China via pipeline and LNG and India via LNG.[102]

Russia is hoping to increase its natural gas exports via LNG to international markets. Unlike pipeline natural gas, LNG must undergo the liquefaction process to convert gas to liquid. LNG is transported exclusively via ships and trucks, necessitating specialized LNG vessels.[103] However, both Russia's liquefaction and transportation capabilities are dependent on specialized, Western-designed components, including propane pre-cooled mixed refrigerant, cryogenic heat exchangers, azipod propulsion units, and gas turbines.[104] Russia's ability to create LNG vessels is also limited, with Russia producing less than 0.5% of ships globally in 2022.[105]

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[100] Kimberly Donovan and Maia Nikoladze, "Russia Sanctions Database: November 2024," Atlantic Council (April 17, 2025), https://www.atlanticcouncil.org/blogs/econographics/russia-sanctions-database-november-2024/. Accessed November 21, 2025.
[101] "Energy system of Russia," International Energy Association, https://www.iea.org/countries/russia. Accessed October 29, 2025.
[102] Samantha Gross and Constanze Stelzenmuller, "Europe's messy Russian gas divorce," Brookings (June 18, 2024), https://www.brookings.edu/articles/europes-messy-russian-gas-divorce/. Accessed November 25, 2025.
[103] "Natural Gas & LNG," Asia Natural Gas & Energy Association, https://angeassociation.com/resource/natural-gas-lng/.
[104] Filip Rudnik, "Unfulfilled ambitions: Russia's LNG sector in the grip of sanctions," Centre for Eastern Studies (June 5, 2023), https://www.osw.waw.pl/en/publikacje/osw-commentary/2023-06-05/unfulfilled-ambitions-russias-lng-sector-grip-sanctions. Accessed November 21, 2025.
[105] Ibid.

Since 2014, Russia has introduced regulations, subsidies, and domestic initiatives to reduce its LNG industry's reliance on foreign components.[106] One such project is Novatek's Arctic LNG 2 Terminal, a project championed by Russia's LNG producer Novatek, which aims to operate three liquefaction trains and establish Russia as a leading world exporter of LNG.[107] The acquisition and production of liquefaction infrastructure further enables Russia to circumvent sanctions, undermine U.S. economic policies, and strengthen Russian geopolitical influence.[108]

U.S. Policies Targeting Russia's LNG Industry

Since Russia's annexation of Crimea in 2014, the United States has implemented economic restrictions, which target Russia's ability to liquefy and transport LNG. These policies restrict individuals, entities and technological components critical to Russia's LNG sector, including azipod propulsion units, drilling rigs, subsea processing equipment, isomerization units, gas-separation equipment, advanced semiconductors, marine propulsion units, and ship-repair parts.[109]

Table 3: U.S. Policies Restricting LNG and Associated Technologies

Policy/Instrument	Year Enacted	Target
Executive Order 13662 – Blocking Property of Additional Persons Contributing to the Situation in Ukraine[110]	March 2014	Sanctions Russian energy sector entities from accessing U.S. goods and financial services
OFAC authorizes EO13660, sanctioning individuals/entities responsible for violating Ukrainian sovereignty[111]	July 2014	Russian and Ukrainian separatist leaders; government officials in Crimea, Donetsk, and

[106] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025; Isha Rao and Max Gruenig, "Sanction-Proof? Russia's Arctic Ambitions and the China Factor," The Arctic Institute (November 21, 2024), https://www.thearcticinstitute.org/sanction-proof-russias-arctic-ambitions-china-factor/. Accessed November 13, 2025.

[107] Mikhail Zhizhin, Morgan Bazilian, and Christopher Elvidge, "Eyes on the Arctic: Satellite Monitoring of the Arctic LNG 2 Terminal," Payne Institute (April 10, 2025), https://payneinstitute.mines.edu/eyes-on-the-arctic-satellite-monitoring-of-the-arctic-lng-2-terminal/. Accessed November 14, 2025.

[108] Andrew Clabough et al., "How the new US sanctions on Russia oil will impact energy markets," Atlantic Council (October 23, 2025), https://www.atlanticcouncil.org/blogs/energysource/how-the-new-us-sanctions-on-russian-oil-will-impact-energy-markets/. Accessed October 29, 2025.

[109] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025.

[110] Administration of Barack Obama, 2014, "Executive Order 13662 – Blocking Property of Additional Persons Contributing to the Situation in Ukraine," Govinfo (March 20, 2014), https://www.govinfo.gov/app/details/CFR-2015-title3-vol1/CFR-2015-title3-vol1-eo13662. Accessed November 13, 2025.

[111] "Ukraine and Russia Sanctions," U.S. Department of State, https://2017-2021.state.gov/ukraine-and-russia-sanctions/. Accessed November 25, 2025.

		Luhansk; banks and companies supporting occupation or annexation activities
Designation of United Shipbuilding Corporation SDN[112]	July 2014	Russian shipbuilding firms accessing financing, parts, and software
EAR amendment – Aug 6 2014[113]	August 2014	Requires licensing for advanced equipment and technology and adds end-use controls for items related to Russian deepwater, Arctic offshore, or shale production projects
BIS adds individuals/entities to the Entity List[114]	September 2014	Russian energy and ship-building entities
OFAC Directive 4 under EO 13662[115]	September 2014	Prohibits the export of goods, services, and technology related to Russian deepwater, Arctic offshore, or shale production projects
Countering America's Adversaries Through Sanctions Act (CAATSA)[116]	August 2017	Codifies sanction authorities related to energy products and services, targets indigenous production
OFAC imposes EO14024, sanctioning entities operating in Russian technology and defense sectors[117]	April 2021	Major defense firms, electronics manufacturers, or software firms supporting military operations

[112] "Announcement of Additional Treasury Sanctions on Russian Financial Institutions and on a Defense Technology Entity," U.S. Department of the Treasury (July 29, 2014), https://home.treasury.gov/news/press-releases/jl2590. Accessed November 13, 2025.
[113] Industry and Security Bureau, "Russian Oil Industry Sanctions and Addition of Person to the Entity List," Federal Register (August 6, 2014), https://www.federalregister.gov/documents/2014/08/06/2014-18579/russian-oil-industry-sanctions-and-addition-of-person-to-the-entity-list. Accessed November 13, 2025.
[114] Industry and Security Bureau, "Russian Sanctions: Addition of Persons to the Entity List and Restrictions on Certain Military End Uses and Military End Users," Federal Register (September 17, 2014), https://www.federalregister.gov/documents/2014/09/17/2014-22207/russian-sanctions-addition-of-persons-to-the-entity-list-and-restrictions-on-certain-military-end. Accessed November 13, 2025.
[115] Office of Foreign Assets Control, "412. What do the prohibitions contained in Directive 4 mean? What is the scope of prohibited services?" U.S. Department of the Treasury (October 31, 2017), https://ofac.treasury.gov/faqs/412. Accessed November 13, 2025.
[116] Office of Foreign Assets Control, "Countering America's Adversaries Through Sanctions Act-Related Sanctions," U.S. Department of the Treasury (August 2, 2017), https://ofac.treasury.gov/sanctions-programs-and-country-information/countering-americas-adversaries-through-sanctions-act-related-sanctions. Accessed November 13, 2025.
[117] Office of Foreign Assets Control, "Publication of Russian Harmful Foreign Activities Sanctions Regulations Determinations," Federal Register (September 25, 2024), https://www.federalregister.gov/documents/2024/09/25/2024-21798/publication-of-russian-harmful-foreign-activities-sanctions-regulations-determinations. Accessed November 13, 2025.

BIS controls the export of items related to Russian defense, aerospace, and maritime sectors; BIS adds 49 military end users to the Entity List[118]	February 2022	Russian defense contractors, shipbuilding firms, and aerospace manufacturers
U.S. announces Global Export Controls Coalition (GECC) to prohibit exports to Russia of marine items and technologies and restricted the passage of Russian-registered/operated ships through their ports/territorial waters.[119]	April 2022	Russian-registered or Russian-operated vessels; shipyards; logistics and shipping companies; state-owned shipping operators, including Sovcomflot
BIS issues "Final Rule", expanding license requirements for Russia under the EAR to all items on the CCL[120]	April 2022	All Russian individuals/entities seeking U.S.-origin items on the Commerce Control List
EO 14071 authorizes OFAC to prohibit U.S. firms/entities from providing maritime services to Russian individuals/entities[121]	April 2022	Russian individuals/entities operating in shipping, insurance, flagging, customs brokering, trading, or finance sectors
BIS formally adds Iceland, Liechtenstein, Norway, and Switzerland to GECC[122]	April 2022	Other Western partners providing maritime services
BIS expands Russian industry sector sanctions to include exports, reexports, and in-country transfers for CCL items[123]	May 2022	Russia defense, energy, aerospace, and maritime firms; imports and distributors of dual-use goods

[118] Bureau of Industry and Security, "Commerce Implements Sweeping Restrictions on Exports to Russia in Response to Further Invasion of Ukraine," U.S. Department of Commerce (February, 24, 2025), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.bis.doc.gov/index.php/documents/about-bis/newsroom/press-releases/2914-2022-02-24-bis-russia-rule-press-release-and-tweets-final/file&ved=2ahUKEwjb55_or52RAxWJmWoFHXTtLgMQFnoECBcQAQ&usg=AOvVaw1CO5qy-FEl_NAF93-TlyGU. Accessed October 28, 2025.

[119] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025.

[120] Industry and Security Bureau, "Expansion of Sanctions Against Russia and Belarus Under the Export Administration Regulations (EAR)," Federal Register, https://www.federalregister.gov/documents/2022/04/14/2022-07937/expansion-of-sanctions-against-russia-and-belarus-under-the-export-administration-regulations-ear. Accessed November 26, 2025.

[121] Office of Foreign Assets Control, "Russian Harmful Foreign Activities Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/faqs/1128. Accessed November 26, 2025.

[122] Kerry B. Contini, Lise S. Test, and Carolina Howard, "BIS Expands Sanctions Against Russia and Belarus and Adds Four Countries to Global Export Controls Coalition," Global Sanctions and Export Controls Blog (April 12, 2022), https://sanctionsnews.bakermckenzie.com/bis-expands-sanctions-against-russia-and-belarus-and-adds-four-countries-to-global-export-controls-coalition/. Accessed October 27, 2025.

[123] Industry and Security Bureau, "Expansion of Sanctions Against Russian Industry Sectors Under the Export Administration Regulations (EAR)," Federal Register (May 11, 2022), https://www.federalregister.gov/documents/2022/05/11/2022-10099/expansion-of-sanctions-against-russian-industry-sectors-under-the-export-administration-regulations. Accessed October 27, 2025.

BIS adds 71 entities to Entity List[124]	June 2022	Defense research institutes; electronics and semiconductor firms; intermediaries in China, Armenia, Turkey linked to Russian procurement networks
BIS imposes export controls on Russian semiconductor and gas turbine engine technologies[125]	August 2022	Russian semiconductor design/manufacturing firms; defense R&D centers; aviation and ship engine manufacturers
Treasury and Commerce expand restrictions to include any individuals/entities operating in Russian construction, architecture, engineering, transportation, and manufacturing sectors[126]	May 2023	Russian individuals/entities operating in design, infrastructure, logistics, or manufacturing services tied to government or defense contracts
OFAC sanctions Joint Stock Company Sovcomflot (Sovcomflot, Russia's state-owned shipping company and fleet operator) and 14 crude oil tankers[127]	February 2024	Sovcomflot and associated vessels
OFAC announces secondary sanctions to include all individuals/entities designated in EO14024[128]	June 2024	Foreign financial institutions; shipping companies; insurers and intermediateness aiding EO14024-designated entities
Treasury and State sanction any individuals/entities operating in the Russian Federation's energy sector; OFAC sanctions major oil and gas producers, Gazprom Neft and Surgutneftegas, their subsidiaries, associated vessels[129]	January 2025	Russian state-owned oil companies, subsidiaries, joint ventures, and oil-carrying vessels involved in export or financial of Russian petroleum

Sources: For links to the source material, please see in-text footnotes. Data was collected from Govinfo, U.S. Department of State, U.S. Department of the Treasury, U.S. Department of Commerce, Federal Register, Wisconsin Project on Nuclear Arms Control, Global Sanctions and Export Controls Blog, and Covington.

[124] Industry and Security Bureau, "Additions of Entities to the Entity List," *Federal Register* (June 6, 2022), https://www.federalregister.gov/documents/2022/06/06/2022-12144/additions-of-entities-to-the-entity-list. Accessed October 27, 2025.
[125] "Commerce Implements New Multilateral Controls on Advanced Semiconductor and Gas Turbine Engine Technologies," *Bureau of Industry and Security* (August 12, 2022), https://www.bis.doc.gov/index.php/component/docman/?task=doc_download&gid=3108. Accessed October 27, 2025.
[126] "New U.S., UK, and EU Sanctions and Export Controls Against Russia and Relates Measures Targeting Belarus and Iran," *Covington* (May 24, 2023), https://www.cov.com/en/news-and-insights/insights/2023/05/new-us-uk-and-eu-sanctions-and-export-controls-against-russia-and-related-measures-targeting-belarus-and-iran. Accessed October 27, 2025.
[127] "U.S. Treasury Designates Russian State-Owned Sovcomflot, Russia's Largest Shipping Company," *U.S. Department of the Treasury* (February 23, 2024), https://home.treasury.gov/news/press-releases/jy2121. Accessed October 27, 2025.
[128] Office of Foreign Assets Control, "Russian Harmful Foreign Activities Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/faqs/topic/6626. Accessed November 26, 2025.
[129] "Treasury Intensifies Sanctions Against Russia by Targeting Russia's Oil Production and Exports," U.S. Department of the Treasury (January 10, 2025), https://home.treasury.gov/news/press-releases/jy2777. Accessed October 27, 2025.

Note: The above table represents the most relevant economic restrictions targeting Russia's LNG sector. For a more exhaustive list of policies, see: "U.S. Office of Foreign Assets Control, "Russia-related Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/sanctions-programs-and-country-information/russia-related-sanctions. Accessed November 26, 2025.

The earliest U.S. policies targeted the Russian LNG sector by progressively restricting Russian access to equipment and services (especially from Western financial institutions), targeting Russian individuals, firms, and vessels, and expanding licensing and Entity List designations.[130] Moreover, the July 2014 designation of United Shipbuilding, August 2014 EAR Amendment, and September 2014 EO 13662 targeted high-value technology chokepoints that support Russian energy sectors. In the years that followed, the United States continued this policy by expanding the scope of restrictions, designating Russian shipbuilding and defense firms to the Entity List in April 2021 with EO 14024.[131]

The most prominent U.S. sanctions and export controls were enacted after Russia's full-scale invasion of Ukraine in 2022, when the United States expanded the policy from targeting specific entities and technologies to a presumption of denial policy with the April 2022 BIS Rule, which expanded Russian controls to include all items on the Commerce Control List (CCL). Additionally, the FDPR restricted not only U.S.-made goods, but any technologies manufactured using U.S. equipment. The policies that followed expanded their scope, shifting from a strategy which restricted specific technologies to ones that covered the entire logistics and shipbuilding ecosystem, including construction, architecture, transportation, and maritime sectors.

Were U.S. policies effective?

U.S. economic restrictions on Russia's LNG sector were largely effective. Early measures that targeted a limited scope of individuals and firms after Russia's 2014 annexation of Crimea did not restrict access to specific goods, but instead restricted Western finance for Russian banks and energy companies, including Gazprombank, VEB, Novatek, and Rosneft.[132] Subsequent restrictions denied Russia's direct access to highly specialized Western components used for LNG liquefaction,

[130] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025.
[131] Foreign Assets Control Office, "Publication of Russian Harmful Foreign Activities Sanctions Regulations Determinations," Federal Register (September 25, 2024), https://www.federalregister.gov/documents/2024/09/25/2024-21798/publication-of-russian-harmful-foreign-activities-sanctions-regulations-determinations. Accessed November 14, 2025; Bureau of Industry and Security, "Commerce Implements Sweeping Restrictions on Exports to Russia in Response to Further Invasion of Ukraine," U.S. Department of Commerce (February 24, 2022), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.bis.doc.gov/index.php/documents/about-bis/newsroom/press-releases/2914-2022-02-24-bis-russia-rule-press-release-and-tweets-final/file&ved=2ahUKEwi_otS8jIuRAxV7k4kEHY-4HCwQFnoECBsQAQ&usg=AOvVaw1CO5qy-FEl_NAF93-TlyGU. Accessed November 14, 2025.
[132] Vitaly Yermakov, "Arctic LNG 2: The litmus test for sanctions against Russian LNG," Oxford Institute for Energy Studies (November 2024), https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/10/Arctic-LNG-2.pdf. Accessed November 26, 2025.

transport, and Arctic shipping. However, loopholes in enforcement, uneven multilateral participation, and reliance on third-party intermediaries have allowed Russian firms to circumvent these restrictions. These workarounds mitigate, but do not eliminate, the impact of U.S. policies, which have contributed to operational delays, increased costs, and recent shutdowns of major projects such as the Arctic LNG-2 liquefaction train.

Table 4 below outlines whether key U.S. restrictions were effective in achieving their intended impact. Effectiveness is assessed based on how these policies, together with prior measures, limit the sustained technological acquisition of LNG infrastructure and related goods.

Table 4: Effectiveness of U.S. Restrictions on Russia

Policy/Instrument	Year Enacted	Intended Impact Achieved?	Explanation of Impact
Executive Order 13662 – Blocking Property of Additional Persons Contributing to the Situation in Ukraine[133]	March 2014	Partially Achieved	Policies delayed financial for energy projects[134]
OFAC authorizes EO13660, sanctioning individuals/entities responsible for violating Ukrainian sovereignty[135]	July 2014	Partially Achieved	Blocking a major state-owned shipbuilder raised the costs of procurement for Western ships[136]
Designation of United Shipbuilding Corporation SDN[137]	July 2014	Partially Achieved	Strengthened licensing for dual-use goods[138]

[133] Administration of Barack Obama, 2014, "Executive Order 13662 – Blocking Property of Additional Persons Contributing to the Situation in Ukraine," Govinfo (March 20, 2014), https://www.govinfo.gov/app/details/CFR-2015-title3-vol1/CFR-2015-title3-vol1-eo13662. Accessed November 13, 2025.
[134] Ibid.
[135] "Ukraine and Russia Sanctions," U.S. Department of State, https://2017-2021.state.gov/ukraine-and-russia-sanctions/. Accessed November 25, 2025.
[136] Ibid.
[137] "Announcement of Additional Treasury Sanctions on Russian Financial Institutions and on a Defense Technology Entity," U.S. Department of the Treasury (July 29, 2014), https://home.treasury.gov/news/press-releases/jl2590. Accessed November 13, 2025.
[138] "U.S. Sanctions Russia's United Shipbuilding Corporation," The Maritime Executive (April 7, 2022), https://maritime-executive.com/article/u-s-sanctions-russia-s-united-shipbuilding-corporation. Accessed December 12, 2025.

EAR amendment – Aug 6 2014[139]	August 2014	Partially Achieved	Expanded individuals/entities but left some firms unlisted, allowed for circumvention[140]
BIS adds individuals/entities to the Entity List[141]	September 2014	Partially Achieved	Regulations that weren't targeted at energy-infrastructure chokepoints allowed for circumvention[142]
OFAC Directive 4 under EO 13662[143]	September 2014	Partially Achieved	Sanctions in critical sectors raised procurement costs and made procurement more difficult[144]
Countering America's Adversaries Through Sanctions Act (CAATSA)[145]	August 2017	Partially Achieved	Disrupted some firms and supply-chains, but Russia continued to operate and source parts via alternate routes[146]
OFAC imposes EO14024, sanctioning entities operating in Russian technology and defense sectors[147]	April 2021	Partially Achieved	Denied direct exports, but Russian firms found workarounds through

[139] Industry and Security Bureau, "Russian Oil Industry Sanctions and Addition of Person to the Entity List," Federal Register (August 6, 2014), https://www.federalregister.gov/documents/2014/08/06/2014-18579/russian-oil-industry-sanctions-and-addition-of-person-to-the-entity-list. Accessed November 13, 2025.
[140] Bureau of Industry and Security, "Expansion of End-User Controls to Cover Affiliates of Certain Listed Entities," Federal Register (September 30, 2025", https://www.federalregister.gov/documents/2025/09/30/2025-19001/expansion-of-end-user-controls-to-cover-affiliates-of-certain-listed-entities. Accessed December 12, 2025.
[141] Industry and Security Bureau, "Russian Sanctions: Addition of Persons to the Entity List and Restrictions on Certain Military End Uses and Military End Users," Federal Register (September 17, 2014), https://www.federalregister.gov/documents/2014/09/17/2014-22207/russian-sanctions-addition-of-persons-to-the-entity-list-and-restrictions-on-certain-military-end. Accessed November 13, 2025.
[142] Kari Crane, "Current U.S. Export Controls Against Russia," Shipping Solutions Software (August 14, 2024), https://shippingsolutionssoftware.com/blog/current-u.s.-export-controls-against-russia. Accessed December 12, 2024.
[143] Office of Foreign Assets Control, "412. What do the prohibitions contained in Directive 4 mean? What is the scope of prohibited services?" U.S. Department of the Treasury (October 31, 2017), https://ofac.treasury.gov/faqs/412. Accessed November 13, 2025.
[144] Ibid.
[145] Office of Foreign Assets Control, "Countering America's Adversaries Through Sanctions Act-Related Sanctions," U.S. Department of the Treasury (August 2, 2017), https://ofac.treasury.gov/sanctions-programs-and-country-information/countering-americas-adversaries-through-sanctions-act-related-sanctions. Accessed November 13, 2025.
[146] Petras Katinas, "The rise of 'shadow' LNG vessels: A new chapter in Russia's sanctions evasion strategy," Centre for Research on Energy and Clean Air (August 23, 2024), https://energyandcleanair.org/the-rise-of-shadow-lng-vessels-a-new-chapter-in-russias-sanctions-evasion-strategy/. Accessed October 29, 2025.
[147] Foreign Assets Control Office, "Publication of Russian Harmful Foreign Activities Sanctions Regulations Determinations," Federal Register (September 25, 2024), https://www.federalregister.gov/documents/2024/09/25/2024-21798/publication-of-russian-harmful-foreign-activities-sanctions-regulations-determinations. Accessed November 13, 2025.

			Chinese, Turkish and Emirati intermediaries[148]
BIS controls the export of items related to Russian defense, aerospace, and maritime sectors; BIS adds 49 military end users to the Entity List[149]	February 2022	Partially Achieved	Official Russian shipping is restricted but continues by way of alternate routes, a "shadow fleet," and non-coalition suppliers[150]
U.S. announces Global Export Controls Coalition (GECC) to prohibit exports to Russia of marine items and technologies and restricted the passage of Russian-registered/operated ships through their ports/territorial waters.[151]	April 2022	Significantly Achieved	Further restricted loopholes to Western insurance, shipping, and maintenance services and raised operating costs[152]
BIS issues "Final Rule", expanding license requirements for Russia under the EAR to all items on the CCL[153]	April 2022	Significantly Achieved	Denial by U.S. firms further increases Russian costs[154]
EO 14071 authorizes OFAC to prohibit U.S. firms/entities from providing maritime services to Russian individuals/entities[155]	April 2022	Significantly Achieved	Prevented new investment in Russia's energy sector, and expanded financial sanctions[156]

[148] "Treasury Hardens Sanctions With 130 New Russian Evasion and Military-Industrial Targets," U.S. Department of the Treasury (November 2, 2023), https://home.treasury.gov/news/press-releases/jy1871. Accessed December 12, 2025.
[149] Bureau of Industry and Security, "Commerce Implements Sweeping Restrictions on Exports to Russia in Response to Further Invasion of Ukraine," U.S. Department of Commerce (February, 24, 2025), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.bis.doc.gov/index.php/documents/about-bis/newsroom/press-releases/2914-2022-02-24-bis-russia-rule-press-release-and-tweets-final/file&ved=2ahUKEwjb55_or52RAxWJmWoFHXTtLgMQFnoECBcQAQ&usg=AOvVaw1CO5qy-FEl_NAF93-TlyGU. Accessed October 28, 2025.
[150] Petras Katinas, "The rise of 'shadow' LNG vessels: A new chapter in Russia's sanctions evasion strategy," Centre for Research on Energy and Clean Air (August 23, 2024), https://energyandcleanair.org/the-rise-of-shadow-lng-vessels-a-new-chapter-in-russias-sanctions-evasion-strategy/. Accessed October 29, 2025.
[151] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025.
[152] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025.
[153] Industry and Security Bureau, "Expansion of Sanctions Against Russia and Belarus Under the Export Administration Regulations (EAR)," Federal Register, https://www.federalregister.gov/documents/2022/04/14/2022-07937/expansion-of-sanctions-against-russia-and-belarus-under-the-export-administration-regulations-ear. Accessed November 26, 2025.
[154] Ibid.
[155] Office of Foreign Assets Control, "Russian Harmful Foreign Activities Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/faqs/1128. Accessed November 26, 2025.
[156] Office of Foreign Assets Control, "Russian Harmful Foreign Activities Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/faqs/1128. Accessed November 26, 2025.

BIS formally adds Iceland, Liechtenstein, Norway, and Switzerland to GECC[157]	April 2022	Partially Achieved	Strengthened restrictions on marine-related transfers, but enforcement gaps within non-GECC countries allowed for circumvention[158]
BIS expands Russian industry sector sanctions to include exports, reexports, and in-country transfers for CCL items[159]	May 2022	Significantly Achieved	Excluded key Russian shipbuilders and logistics firms from foreign procurement networks[160]
BIS adds 71 entities to Entity List[161]	June 2022	Partially Achieved	Curtailed access to advanced propulsion systems and control electronics, though Russia able to substitute with lower-quality imports from China[162]
BIS imposes export controls on Russian semiconductor and gas turbine engine technologies[163]	August 2022	Significantly Achieved	Disrupted access to ship repair, port construction, and engineering services[164]

[157] Kerry B. Contini, Lise S. Test, and Carolina Howard, "BIS Expands Sanctions Against Russia and Belarus and Adds Four Countries to Global Export Controls Coalition," Global Sanctions and Export Controls Blog (April 12, 2022), https://sanctionsnews.bakermckenzie.com/bis-expands-sanctions-against-russia-and-belarus-and-adds-four-countries-to-global-export-controls-coalition/. Accessed October 27, 2025.
[158] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025.
[159] Industry and Security Bureau, "Expansion of Sanctions Against Russian Industry Sectors Under the Export Administration Regulations (EAR)," Federal Register (May 11, 2022), https://www.federalregister.gov/documents/2022/05/11/2022-10099/expansion-of-sanctions-against-russian-industry-sectors-under-the-export-administration-regulations. Accessed October 27, 2025.
[160] Ibid.
[161] Industry and Security Bureau, "Additions of Entities to the Entity List," *Federal Register* (June 6, 2022), https://www.federalregister.gov/documents/2022/06/06/2022-12144/additions-of-entities-to-the-entity-list. Accessed October 27, 2025.
[162] Isha Rao and Max Gruenig, "Sanction-Proof? Russia's Arctic Ambitions and the China Factor," The Arctic Institute (November 21, 2024), https://www.thearcticinstitute.org/sanction-proof-russias-arctic-ambitions-china-factor/. Accessed November 13, 2024.
[163] "Commerce Implements New Multilateral Controls on Advanced Semiconductor and Gas Turbine Engine Technologies," *Bureau of Industry and Security* (August 12, 2022), https://www.bis.doc.gov/index.php/component/docman/?task=doc_download&gid=3108. Accessed October 27, 2025.
[164] Paul Esau and Katie Gorman, "Sanctioned Sector Analysis: Russian Shipping," Wisconsin Project on Nuclear Arms Control (November 4, 2024), https://www.wisconsinproject.org/sanctioned-sector-analysis-russian-shipping/. Accessed October 27, 2025.

Treasury and Commerce expand restrictions to include any individuals/entities operating in Russian construction, architecture, engineering, transportation, and manufacturing sectors[165]	May 2023	Partially Achieved	Sovcomflot restricted, but Russia retains capacity via shadow fleet and third-party vessels[166]
OFAC sanctions Joint Stock Company Sovcomflot (Sovcomflot, Russia's state-owned shipping company and fleet operator) and 14 crude oil tankers[167]	February 2024	Significantly Achieved	Increased compliance risk for intermediaries[168]
OFAC announces secondary sanctions to include all individuals/entities designated in EO14024[169]	June 2024	Significantly Achieved	Severely disrupted Russian oil logistics and marine operations by restricting vessel insurance, financing, and spare part access[170]

Sources: For links to the source material, please see in-text footnotes. Data was collected from Govinfo, U.S. Department of State, U.S. Department of the Treasury, U.S. Department of Commerce, Federal Register, Wisconsin Project on Nuclear Arms Control, Global Sanctions and Export Controls Blog, and Covington.
Note: The above table represents the most relevant economic restrictions targeting Russia's LNG sector. For a more exhaustive list of policies, see: "U.S. Office of Foreign Assets Control, "Russia-related Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/sanctions-programs-and-country-information/russia-related-sanctions. Accessed November 26, 2025.

The initial sanctions policy which targeted those individuals/firms involved in the 2014 annexation of Crimea also targeted major Russian financial institutions and energy companies. Alone, these policies were not effective in limiting Russian access to maritime goods and services, but they were effective in delaying liquefaction projects.[171] The policies, which did not affect existing debt, prompted Russian firms to find funding from alternate partnerships, such as a $12 billion loan secured by Novatek from the Export-Import Bank of China and the China Development Bank.[172] By

[165] "New U.S., UK, and EU Sanctions and Export Controls Against Russia and Relates Measures Targeting Belarus and Iran," *Covington* (May 24, 2023), https://www.cov.com/en/news-and-insights/insights/2023/05/new-us-uk-and-eu-sanctions-and-export-controls-against-russia-and-related-measures-targeting-belarus-and-iran. Accessed October 27, 2025.
[166] Petras Katinas, "The rise of 'shadow' LNG vessels: A new chapter in Russia's sanctions evasion strategy," Centre for Research on Energy and Clean Air (August 23, 2024), https://energyandcleanair.org/the-rise-of-shadow-lng-vessels-a-new-chapter-in-russias-sanctions-evasion-strategy/. Accessed October 29, 2025.\
[167] "U.S. Treasury Designates Russian State-Owned Sovcomflot, Russia's Largest Shipping Company," *U.S. Department of the Treasury* (February 23, 2024), https://home.treasury.gov/news/press-releases/jy2121. Accessed October 27, 2025.
[168] Industry and Security Bureau, "Expansion of Sanctions Against Russian Industry Sectors Under the Export Administration Regulations (EAR)," Federal Register (May 11, 2022), https://www.federalregister.gov/documents/2022/05/11/2022-10099/expansion-of-sanctions-against-russian-industry-sectors-under-the-export-administration-regulations. Accessed October 27, 2025.
[169] Office of Foreign Assets Control, "Russian Harmful Foreign Activities Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/faqs/topic/6626. Accessed November 26, 2025.
[170] Ibid.
[171] Vitaly Yermakov, "Arctic LNG 2: The litmus test for sanctions against Russian LNG," Oxford Institute for Energy Studies (November 2024), https://www.oxfordenergy.org/wpcms/wp-content/uploads/2024/10/Arctic-LNG-2.pdf. Accessed November 26, 2025.
[172] Ibid.

targeting few individuals and entities, the policies also allowed for circumvention by other parties and industries.[173]

Most policies partially achieved their intended impact by restricting direct access to Russian LNG-specific goods but allowing for indirect access via non-coalition countries, third-party intermediaries, and the Russian "shadow fleet." Executive Order 12024 (April 2021), the formation of GECC (April 2022), and repeated BIS designation expansions restricted Russian access to highly-specialized goods made by Western firms. However, Russian firms were able to circumvent these restrictions by sourcing components from non-coalition countries, namely China. According to an article by the Arctic Institute, Chinese companies hold significant stakes in Russia's Arctic energy projects, with a combined 30% in Yamal LNG and 20% in Arctic LNG-2.[174] When Russian firms are unable to acquire the requisite Western components for liquefaction and transport, they pivot to Chinese suppliers. For example, the same Arctic Institute article explains, "When sanctions cut off access to Western gas turbines from Baker Hughes [in November 2023], Novatek swiftly pivoted to Chinese supplier Harbin Guanghan." Because of U.S. and coalition policies, Novatek reconfigured the Arctic LNG 2 liquefaction train to operate with Chinese components. However, the reconfiguration delayed operations and raised costs.

Additionally, Russia utilizes its shadow fleet, otherwise referred to as a "ghost fleet" or "dark fleet" to circumvent restrictions. While the shadow fleet was originally operationalized to circumvent the G7 price-cap on crude-oil, Russia uses its collection of LNG shadow vessels to circumvent restrictions on Western-provided maritime services, insurance, vessel classification, and port access. By intentionally obfuscating ownership, flag, or cargo origin by turning off Automatic Identification System (AIS), carrying out ship-to-ship transfers, and re-reflagging, the LNG shadow fleet ensures the continued export of LNG.[175] The vessels in the shadow fleet are older and limited in capability. Of the Russian shadow fleet's 9 LNG vessels, only 4 are ice-class LNG tankers, meaning they are equipped with specialized technology which enable ships to travel along the Northern Sea Route (NSR) during winter months.[176] The NSR is the fastest route from Russia's liquefaction facilities to LNG markets in India and China, taking approximately 33 days to reach China while the longer route through the Suez Canal takes 63 days.[177]

[173] Robin Brooks and Ben Harris, "Where did Russia's shadow fleet come from?" Brookings (February 27, 2025), https://www.brookings.edu/articles/where-did-russias-shadow-fleet-come-from/. Accessed October 21, 2025.
[174] Isha Rao and Max Gruenig, "Sanction-Proof? Russia's Arctic Ambitions and the China Factor," The Arctic Institute (November 21, 2024), https://www.thearcticinstitute.org/sanction-proof-russias-arctic-ambitions-china-factor/. Accessed November 13, 2024.
[175] "Russia Pushes 'Shadow Fleet' To Limit As LNG Carrier Struggles Through Early Arctic Ice On Northern Sea Route," fullaventnews.com (November 3, 2025), https://fullavantenews.com/russia-pushes-shadow-fleet-to-limit-as-lng-carrier-struggles-through-early-arctic-ice-on-northern-sea-route/. Accessed November 5, 2025.
[176] Ibid.
[177] Petras Katinas, "The rise of 'shadow' LNG vessels: A new chapter in Russia's sanctions evasion strategy," Centre for Research on Energy and Clean Air (August 23, 2024), https://energyandcleanair.org/the-rise-of-shadow-lng-vessels-a-new-chapter-in-russias-sanctions-evasion-strategy/. Accessed October 29, 2025.

Third party intermediaries also play a role in Russian circumvention tactics. European shipyards, including the Damen shipyard in France and Fayard A/S shipyard in Demark, have helped designated entities circumvent restrictions by providing repair services and dry dock facilities to Russian ice-class tankers.[178] Because of the shipyards' proximate location to Russian shipping routes and their capacity to handle the large Arc7s, they are the only ones capable of providing such services to Russian vessels.[179] The two yards have serviced 14 out of the 15 specialized ice-class LNG tankers that ship from the Russian majority owned Yamal LNG facility on Russia's far northern coast.

The most effective U.S. policies—the EO 14071 issued in February 2022, the Final Rule imposed in April 2022, Treasury and Commerce designations of specific sectors and goods, and secondary sections initiated in June 2024—exploited Russia's disadvantage in the production of ice-class LNG tankers and restricted other trade outlets. The Centre for Research on Energy and Clean Air estimates, "The current [shadow] fleet would fall short of meeting the demands of the Arctic LNG-2 project output. Specifically, the nine vessels would be capable of transporting approximately 53% of the output to China and 72% to India, not accounting for the seasonal limitations of Arctic navigation."[180]

The recent closure of commercial operations at Novatek's Arctic LNG 2 project indicates the success of U.S. policies in denying Russian access to maritime technology fit for Arctic conditions. One report by Kpler explains, "The shutdown of the plant is ultimately a reflection of a lack of appetite from buyers and a lack of Arc7 ice-class vessels needed to lift LNG during the winter months."[181] This is likely due to Western sanctions on technology exports targeting the Russian shipbuilding sector, with High North News illustrating, "the sanctions target azipod propulsion units, of which each vessel uses three for high maneuverability and power levels of 51MW [megawatts]."[182]

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[178] Alice Hancock and Chris Cook, "EU shipyards are fixing Russia's Arctic LNG tankers," Financial Times (January 13, 2025), https://www.ft.com/content/1604de31-5c3e-4d91-9237-7ef63dc887cc. Accessed November 5, 2025.
[179] Jennifer Jun, "Russia's Arctic LNG Infrastructure: Development and Operational Analysis," Tearline.mil (July 7, 2025), https://www.tearline.mil/public_page/russias-arctic-lng-infrastructure-development-and-operational-analysis. Accessed November 5, 2025.
[180] Petras Katinas, "The rise of 'shadow' LNG vessels: A new chapter in Russia's sanctions evasion strategy," Centre for Research on Energy and Clean Air (August 23, 2024), https://energyandcleanair.org/the-rise-of-shadow-lng-vessels-a-new-chapter-in-russias-sanctions-evasion-strategy/. Accessed October 29, 2025.
[181] "Russia's Novatek shuts down commercial operation at Arctic LNG 2 train," Gas Processing & LNG (October 28, 2024), https://gasprocessingnews.com/news/2024/10/russias-novatek-shuts-down-commercial-operation-at-arctic-lng-2-train/. Accessed November 5, 2025.
[182] Malte Humpert, "Western Sanctions Could Inadvertently Redirect Russian LNG to Europe as Novatek Faces Shortage of LNG Carriers," High North News (December 19, 2022), https://www.highnorthnews.com/en/western-sanctions-could-inadvertently-redirect-russian-lng-europe-novatek-faces-shortage-lng. Accessed October 27, 2025; "Russian Shipyard to Deliver Critically Needed Arc7 LNG Carriers for Arctic LNG 2," High North News (June 3, 2024), https://www.highnorthnews.com/en/russian-shipyard-deliver-critically-needed-arc7-lng-carriers-arctic-lng-2. Accessed November 5, 2025; Jennifer Jun, "Russia's Arctic LNG Infrastructure: Development and Operational Analysis," Tearline.mil (July 7, 2025), https://www.tearline.mil/public_page/russias-arctic-lng-infrastructure-development-and-operational-analysis. Accessed November 5, 2025.

In response to Western economic restrictions, the Russian state shipping company Sovcomflot announced the production of the state's first Russian-built ice-class tanker for LNG in June 2025.[183] While Russia has announced numerous sea trials for its indigenous ice-class LNG vessels, as of December 2025, the vessels are still undergoing testing and are not yet operational.

Lessons Learned from Policies Targeting Russian LNG Projects

U.S. policies have proven most effective when:

- targeting high-complexity, low-substitutability goods
- targeting distinct assets which are limited in quantity
- exploiting Western-dominated technological chokepoints

U.S. policies have proven less effective when:

- failing to coordinate enforcement with allies and allied entities

U.S. policies proved most effective when targeting high-complexity, low-substitutability goods (highly specialized goods that have few readily available alternatives), instead of broadly restricting market access. U.S. export controls on advanced maritime systems, like azipod propulsion units and ice-class hull technologies, directly constrained Russia's ability to sustain Arctic LNG operations, forcing the shutdown of major projects. Unlike the crude-oil supply chain, where Russia has been able to offset sanctions through an expansive and easily repurposed shadow fleet, the LNG supply chain is constrained by the Northern Sea Route and technological chokepoints.[184] Because LNG-related components are not commercially ubiquitous and are subject to strict export controls, Russia cannot easily substitute or replicate them. Unlike other goods, LNG carriers take about 4 to 5 years to construct and rely on controlled Western technologies such as cargo containment systems, ice-class hull design and reinforcement technology, re-liquification systems, dual-fuel diesel-electric and LNG-fueled engines.[185] Unable to quickly acquire or replace sanctioned ships, Russia has kept older vessels active, increasing their susceptibility to wear and corrosion.

[183] "First Russian-built ice-class LNG tanker to launch this year, Ifx reports," Reuters (June 25, 2025), https://www.reuters.com/business/energy/first-russian-built-ice-class-lng-tanker-launch-this-year-ifx-reports-2025-06-25/. Accessed September 10, 2025.
[184] Filip Rudnik, "The effect of the sanctions: the Russian LNG sector's problems," OSW Center for Eastern Studies (March 7, 2025), https://www.osw.waw.pl/en/publikacje/osw-commentary/2024-03-07/effect-sanctions-russian-lng-sectors-problems. Accessed November 12, 2025.
[185] Vitaly Yermakov, "Arctic LNG 2: The litmus test for sanctions against Russian LNG," The Oxford Institute for Energy Studies (October 2024), https://www.google.com/url?sa=t&source=web&rct=j&opi=89978449&url=https://www.oxfordenergy.org/publications/arctic-lng-2-the-litmus-test-for-sanctions-against-russian-lng/&ved=2ahUKEwjdpLmIsZ2RAxWpMDQIHWmUIMAQFnoECAwQAQ&usg=AOvVaw0af-rQHquU2DLLZ4H5r_Bk. Accessed November 12, 2025.

Additionally, the scale and structure of the LNG shipping industry make it easier to monitor and enforce sanctions. The Centre for Research on Energy and Clean Air explains:

> "The LNG tankers' fleet is significantly smaller than oil tankers, making monitoring, tracking, and sanctioning these vessels much more feasible. The limited number of ships involved means that Western authorities have a greater chance to enforce sanctions rigorously and prevent Russia from developing a similar workaround in the LNG sector."[186]

LNG carriers, especially ice-class vessels, are distinct, individually named assets that don't easily blend with global traffic. In addition, they require specialized port infrastructure, and there are few terminals capable of receiving them. The centralized structure of the industry, characterized by long-term contracts and state-linked firms, creates clear enforcement paths for economic restrictions.[187]

Allied enforcement efforts have been relatively effective in coordinating enforcement among GECC members to restrict access to Western insurance, financing, and maritime services. However, enforcement is weakened when third parties outside the coalition provide assistance to Russia with ship repair, reflagging, or port services. For example, an article by Brookings explains, "Russia's attempts to purchase hundreds of aging tankers—often approaching the end of their useful life—has been aided by willingness of Western shipowners to sell vessels into the Russian fleet, with an outsized contribution by EU shippers in general and Greeks in particular."[188] These actors enable Russia to expand and sustain its shadow fleet, undermining the impact of allied sanctions despite strong intra-coalition coordination.

Russia currently operates two LNG liquefaction facilities, with proposals to open three additional plants. Ultimately, U.S. policy has succeeded in denying Russian access to viable methods to transport LNG via ice-class LNG carriers. While Russia continues to pursue indigenous methods of exporting LNG through the Arctic, U.S. restrictions have effectively constrained Russia's LNG sector.

[186] Petras Katinas, "The rise of 'shadow' LNG vessels: A new chapter in Russia's sanctions evasion strategy," Centre for Research on Energy and Clean Air (August 23, 2024) https://energyandcleanair.org/the-rise-of-shadow-lng-vessels-a-new-chapter-in-russias-sanctions-evasion-strategy/. Accessed October 29, 2025.
[187] Ibid.
[188] Robin Brooks and Ben Harris, "The race to sanction Russia's growing shadow fleet," Brookings (April 25, 2025), https://www.brookings.edu/articles/the-race-to-sanction-russias-growing-shadow-fleet/. Accessed November 12, 2025.

Case Study #3: Iranian Drone Innovation

This case study examines the impact of U.S. economic policies on Iranian drone acquisition. The tactics used by Iran to circumvent U.S. policies—reverse engineering, illicit trading, and indigenous innovation—have enabled Iran's drone acquisition. While Iran remains capable of producing unmanned autonomous vehicles (UAVs) at scale, U.S. restrictions have limited some qualitative improvements in UAV production.

Background

The case of Iran exemplifies a broader U.S. strategy of economic isolation whereby the U.S. seeks to restrict Iran's access to international financial systems, limit its ability to trade with other nations, and pressure its government with economic restrictions to influence its behavior on the global stage. Unlike the case of China, where the United States uses targeted policies to restrict the trade of goods related to advanced semiconductors and their production, U.S. policy towards Iran seeks to limit the trade of virtually all goods to Iranian entities with the United States. Since the 1979 Revolution, the Islamic Republic of Iran has emerged as an oppressive theocracy with clear strategic objectives: expelling Western influence from the MENA (Middle East North Africa) region, dismantling the state of Israel, and supporting the creation of a Palestinian state under the authority of armed proxy groups.[189] Iran pursues a military strategy of "forward defense" whereby it projects power beyond its borders via drones and ballistic missiles, naval guerrilla tactics, cyber technologies, and non-state proxy allies.[190]

In 2023, Iran released a Five-Year Development Plan which announced the importance of combat drone technology in achieving Iran's strategic objectives.[191] Drones, also called unmanned autonomous vehicles (UAVs) or unmanned autonomous systems (UASs), are aircraft that operate without any passengers or crew on board. They may be controlled remotely by receiving commands from a pilot in real time, or autonomously by executing pre-programmed instructions. Compared to manned aircraft, Iran's drones are relatively cheap to produce, making them expendable, though larger drones can be expensive to produce.[192] Their components are generally commercially

[189] Utku Cakirozer, "2025 – REVISED – IRAN'S THREAT TO REGIONAL AND EURO-ATLANTIC SECURITY," NATO Parliamentary Assembly (September 11, 2025), https://www.nato-pa.int/document/2025-irans-threat-regional-and-euro-atlantic-security-gsm-report. Accessed October 6, 2025; John Ghazvinian, American and Iran: A History, 1720 to the Present (New York, NY: Knopf, 2020).

[190] Umud Shokri, "Iran's deterrence doctrine: From horizontal resilience to vertical strength," Middle East Monitor (January 15, 2025), https://www.middleeastmonitor.com/20250115-irans-deterrence-doctrine-from-horizontal-resilience-to-vertical-strength/. Accessed October 6, 2025.

[191] Shahram Akbarzadeh, "Iran's Missile and Drone Program Disrupting U.S. Aerial Hegemony," Middle East Council on Global Affairs (July, 2024), https://mecouncil.org/publication/irans-missile-and-drone-program-disrupting-u-s-aerial-hegemony/. Accessed October 17, 2025; Michael Rubin, "A Short History of the Iranian Drone Program," American Enterprise Institute (August 2020), https://www.aei.org/research-products/report/a-short-history-of-the-iranian-drone-program/. Accessed October 6, 2025.

[192] "The Iranian Drone Threat," United Against Nuclear Iran, https://www.unitedagainstnucleariran.com/The-iranian-drone-threat. Accessed October 16, 2025.

available and include numerous technologies that are dual-use, including frames, motors, propellers, electronic speed controllers, flight controllers, batteries, sensors, GPS modules, and cameras.[193]

Iran's military drones come in a variety of models that serve different functions: suicide drones, such as Iran's Shahed-136, Arash, and Ababil-T, perform as loitering munitions or cruise missiles; surveillance drones, including the Ababil-3, the Mohajer-2, and the Shahed-171, conduct intelligence, surveillance, and reconnaissance (ISR) operations; and unmanned combat aerial vehicles (UCAVs), such as the Mohajer-6, Shahed-129, or Kamas-12, are reusable drones that conduct surveillance and fire munitions.[194] Many military drones can integrate secure satellite communications, advanced targeting systems, and semi-autonomous navigation capabilities that allow for long-duration missions across contested environments. This paper, when referring to drones, UAVs, or UASs, references such military drones.[195]

The Islamic Republic has come a long way since it first produced Ababil-1 and Mohajer-1 drones in 1986 to aid in the Iran-Iraq War. In 2019, the Defense Intelligence Agency assessed in their "Iran Military Power Study" that Iran was pursuing increasingly numerous and capable UAVs and proliferating them to the Houthis in Yemen as well as to other militia groups in Iraq and Syria.[196] Around the same time, Iran conducted its largest UAV exercise to date, launching 50 offensive UAVs in a simultaneous combat operation 600 miles from their controllers.[197]

Iranian-made drones have since proliferated throughout the Middle East and beyond, featuring in Russia's War in Ukraine, the Syrian Civil War, and in 2019 strikes against Saudi oil installations.[198] In

[193] "All Components of a Drone: A Detailed Guide," Drone Universities, https://www.droneuniversities.com/components-of-a-drone/. Accessed October 17, 2025.
[194] "Clipping Tehran's Wings: How Supply-Side Controls Can Impede the Iranian Drone Program," Iran Watch (February 15, 2023), https://www.iranwatch.org/our-publications/roundtables/clipping-tehrans-wings-how-supply-side-controls-can-impede-iranian-drone-program. Accessed October 16, 2025; "Roster of Iran's Drones," United States Institute of Peace (April 12, 2024), https://iranprimer.usip.org/blog/2024/feb/02/roster-iran%E2%80%99s-drones. Accessed October 20, 2025.
[195] Kelley Sayler, "A World of Proliferated Drones: A Technology Primer," Center for a New American Security (June 2015), https://www.cnas.org/publications/reports/a-world-of-proliferated-drones-a-technology-primer. Accessed October 13, 2025.
[196] Daniel E. Mouton, "Iranian drones have proliferated under US watch," Atlantic Council (April 2, 2024), https://www.atlanticcouncil.org/blogs/iransource/iran-drones-uavs-proliferation-us-policy/. Accessed October 16, 2025; "Iran Military Power: Ensuring Regime Survival and Securing Regional Dominance," Defense Intelligence Agency, (August 2019). Accessed October 16, 2025.
[197] Michael Rubin, "Iran Conducts Its Largest UAV Exercise," American Enterprise Institute (May 1, 2019), https://www.aei.org/articles/iran-conducts-its-largest-uav-exercise/. Accessed October 16, 2025.
[198] "Russia doubles down on the *Shahed,*" International Institute for Security Studies (April 14, 2025), https://www.iiss.org/online-analysis/military-balance/2025/04/russia-doubles-down-on-the-shahed/. Accessed December 10, 2025; Ali Haj Suleiman and Husam Hezaber, "The Syrian regime is stepping up its use of suicide drones," Al Jazeera (February 27, 2024), https://www.aljazeera.com/news/2024/2/27/the-syrian-regime-is-stepping-up-its-use-of-suicide-drones. Accessed December 10, 2025; Ben Hubbard, Palko Karasz, and Stanely Reed, "Two Major Saudi Oil Installations Hit by Drone Strike, and U.S. Blames Iran," New York Times (September 14, 2019), https://www.nytimes.com/2019/09/14/world/middleeast/saudi-arabia-refineries-drone-attack.html. Accessed December 10, 2025.

April 2024, Iran launched over 170 drones towards Israel as a retaliatory measure for Israeli strikes in Syria that struck Iranian generals.[199] Moreover, partnerships with Iran have provided Venezuela and Sudan the designs to the Mohajer-2 and Ababil-3, respectively.[200] Iranian drone acquisition, and the subsequent proliferation to U.S. adversaries and non-state proxies hinders U.S. and allied efforts to ensure their regional security, combat terrorism, counter arms proliferation, and ensure freedom of navigation for global energy supplies and commercial shipping.[201]

U.S. Policies Restricting Access

To restrict Iranian UAV acquisition, the U.S. imposed the policies listed below in Table 5, including broad export controls, arms embargoes, sanctions, and control-list entries, which may or may not specifically mention UAVs, but govern their development, transfer, or use. The policies encompass a strategy that restricts the transfer of all dual-use goods to Iran instead of controlling for specific goods.[202]

Table 5: U.S. Policies Impacting Iranian UAS Acquisition

Policy/Instrument	Year Enacted	Target
United States bans Iranian exports to the United States and freezes $12 billion in Iranian assets[203]	November 1979	Entire Iranian economy; Iranian government and state-owed financial assets
U.S. Department of State designates Iran a state sponsor of terrorism[204]	January 1984	Iranian government; financial system; Iranian-linked entities abroad

[199] Ben Hubbard et al., "Two Major Saudi Oil Installations Hit by Drone Strike, and U.S. Blames Iran," New York Times (September 14, 2019), https://www.nytimes.com/2019/09/14/world/middleeast/saudi-arabia-refineries-drone-attack.html. Accessed October 6, 2025; Matthew Bint and Fabian Hinz, "Russia doubles down on the *Shahed*," Institute for International and Strategic Studies (April 14, 2025), https://www.iiss.org/online-analysis/military-balance/2025/04/russia-doubles-down-on-the-shahed/. Accessed October 6, 2025; U.S. Naval Forces Central Command Public Affairs, "U.S. Navy Analysis Confirms Iranian Link to Drone Attack," U.S. Naval Forces Central Command (November 22, 2022), https://www.cusnc.navy.mil/Media/News/Display/Article/3225652/us-navy-analysis-confirms-iranian-link-to-drone-attack/. Accessed October 6, 2025; Ali Jah Suleiman and Husam Hezber, "The Syrian regime is stepping up its use of suicide drones," Al Jazeera (February 27, 2024), https://www.aljazeera.com/news/2024/2/27/the-syrian-regime-is-stepping-up-its-use-of-suicide-drones. Accessed October 6, 2025.

[200] Michael Rubin, "Iran Conducts Its Largest UAV Exercise," American Enterprise Institute (May 1, 2019), https://www.aei.org/articles/iran-conducts-its-largest-uav-exercise/. Accessed October 16, 2025.

[201] "The Iranian Drone Threat," United Against Nuclear Iran, *https://www.unitedagainstnucleariran.com/The-iranian-drone-threat*. Accessed October 16, 2025.

[202] "Timeline of U.S. Sanctions," *The Iran Primer* (February 24, 2025), https://iranprimer.usip.org/resource/timeline-us-sanctions. On October 14, 2025; Ashish Kumar Sen, "A Brief History of Sanctions on Iran," Atlantic Council (May 8, 2018), https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 14, 2025.

[203] Ibid.

[204] Ibid.

Iran-Iraq Arms Nonproliferation Act opposes the transfer of any goods or technology related to weapons of mass destruction (WMD) to Iran or Iraq[205]	October 1992	WMD-related industries; military suppliers; dual-use goods exporters
Executive Order 13224 freezes the assets of foreign terrorists/terrorist entities and associated individuals/entities[206]	September 2001	Foreign terrorists, terrorist organizations, and individuals/entities supporting terrorism
Executive Order 13382 freezes the assets of individuals and entities involved in the proliferation of CBRNs and related good and associate individuals/entities[207]	July 2005	Individuals/entities involved in WMD proliferation, including Iranian defense and scientific institutions
Executive Orders 13553, 13574, 13590, 13599, 13606, 13608 and 13645 expand U.S. sanctions by blocking assets, restricting trade and financial transactions, and targeting individuals and entities which support Iranian activities[208]	July 2005, September 2010, May 2011, November 2011, February 2012, April 2012, May 2012, June 2013	Iranian government; energy, petrochemical, telecommunications, and banking sectors; human rights violators; Iranian Revolutionary Guard Corps (IRGC) affiliates
Executive Order 13871 blocked transactions with Iranian iron, steel, aluminum, and copper sectors[209]	May 2018	Iranian iron, steel, aluminum, and copper industries
Executive Order 13949 authorized secondary sanctions on entities supporting Iran's conventional arms programs[210]	September 2020	Individuals/entities supporting Iranian convention arms programs, including foreign suppliers
OFAC announces sanctions targeting individuals and entities involved with IRGCs UAV program[211]	October 2021	IRGC drone programs

[205] " Timeline of U.S. Sanctions," *The Iran Primer* (February 24, 2025), https://iranprimer.usip.org/resource/timeline-us-sanctions. On October 14, 2025; Ashish Kumar Sen, "A Brief History of Sanctions on Iran," Atlantic Council (May 8, 2018), https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 14, 2025.
[206] "Executive Order 13224," *U.S. Department of State*, https://www.state.gov/executive-order-13224. Accessed October 15, 2025.
[207] "Blocking Property of Weapons of Mass Destruction Proliferators and Their Supports," Federal Register (July 1, 2005), https://www.federalregister.gov/documents/2005/07/01/05-13214/blocking-property-of-weapons-of-mass-destruction-proliferators-and-their-supporters. Accessed October 15, 2025.
[208] "Timeline of U.S. Sanctions," The Iran Primer (February 24, 2025), https://iranprimer.usip.org/resource/timeline-us-sanctions.
[209] Ibid.
[210] Industry and Security Bureau, "Export Control Measures Under the Export Administrations Regulations (EAR) To Address Iranian Unmanned Aerial Vehicles (UAVs) and Their Use by the Russian Federation Against Ukraine," Federal Register (February 27, 2023), https://www.federalregister.gov/documents/2023/02/27/2023-03930/export-control-measures-under-the-export-administration-regulations-ear-to-address-iranian-unmanned. Accessed October 15, 2025.
[211] "U.S. issues Iran-related sanctions over drone program," Reuters (October 29, 2021), https://www.reuters.com/world/middle-east/us-issues-new-iran-related-sanctions-treasury-website-2021-10-29/. Accessed October 16, 2025; Office of Foreign Assets Control, "Counter Terrorism Designations and Designation Update;

BIS expands EAR to address Iranian UAVs and their use by Russia in Ukraine[212]	February 2023	Iranian UAV manufacturers; intermediaries in Russia and elsewhere supplying components
OFAC publishes "Guidance to Industry on Iran's UAV-Related Activities"[213]	June 2023	U.S. private-sector industry, manufacturers, exporters, distributors, financial institutions whose components could be diverted for UAV production
BIS issues the Iran Foreign Direct Product Rule, restricting the exports of U.S.-origin goods to Iran[214]	April 2024	Global entities exporting U.S.-origin goods or technology to Iran; Iranian defense and UAV industries
OFAC expands sanctions to include entities involved in Iran's UAV program[215]	April 2024	Iranian UAV developers, manufacturers, and procurement networks
OFAC designates five individuals/entities in Iran, Hong Kong, Taiwan, and China for supporting HESA's procurement[216]	July 2025	Iran government (Ministry of Defense and Armed Forces Logistics, MODAFL); HESA; associated foreign entities
Reinterpretation of MTCR for UAS Exports, classifying UAS as military aircraft instead of missiles[217]	September 2025	UAV producers and exporters; foreign firms seeking export licenses for UAVs to Iran

Iran-related Designations; Non-Proliferation Designations," U.S. Department of the Treasury (October 29, 2021), https://ofac.treasury.gov/recent-actions/20211029. Accessed October 16, 2025.

[212] Industry and Security Bureau, "Export Control Measures Under the Export Administration Regulations (EAR) To Address Iranian Unmanned Aerial Vehicles (UAVs) and Their Use by the Russian Federation Against Ukraine," Federal Register (February 27, 2023), https://www.federalregister.gov/documents/2023/02/27/2023-03930/export-control-measures-under-the-export-administration-regulations-ear-to-address-iranian-unmanned. Accessed November 26, 2025.

[213] Office of Foreign Assets Control, "Guidance to Industry on Iran's UAV-Related Activities," U.S. Department of the Treasury (June 9, 2023), Guidance to Industry on Iran's UAV-Related ActivitiesOffice of Foreign Assets Control (.gov)https://ofac.treasury.gov › recent-actions › 20230609. Accessed November 26, 2025.,

[214] Industry and Security Bureau, "Iran Foreign Direct Product Rule," Federal Register (July 26, 2024), Iran Foreign Direct Product RuleFederal Register (.gov)https://www.federalregister.gov › 2024-16566 › iran-fo.... Accessed November 26, 2025.

[215] Office of Foreign Assets Control, "Iran Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/sanctions-programs-and-country-information/iran-sanctions. Accessed October 15, 2025.

[216] "Treasury Sanctions Global Network Supporting Iran's Military UAV Program," Iran Watch (July 31, 2025), https://www.iranwatch.org/library/governments/united-states/executive-branch/department-treasury/treasury-sanctions-global-network-supporting-irans-military-uav-program. Accessed October 16, 2025.

[217] Tom Karako, "A Marie Kondo Moment for MTCR: Tidying Up the U.S. Approach to Missile Proliferation," Center for Strategic and International Studies (September 23, 2025), https://www.csis.org/analysis/marie-kondo-moment-mtcr. Accessed October 15, 2025.

BIS issues the "50% Rule" which expands end-use controls to any entities that are majority owned by parties on the entity list[218]	September 2025 – November 2025[219]	Entities majority-owned (≥50%) by sanctioned or listed Iranian individuals/entities
BIS adds Chinese, Hong-Kong, and Turkish entities to the Entities List for their role in facilitating unmanned aircraft procurement networks in Iran[220]	October 2025	Chinese, Hong Kong, and Turkish intermediaries enabling Iranian UAV procurement and supply chains; HESA (Iran Aircraft Manufacturing Industrial Company)

Sources: For links to the source materials, please see in-text footnotes. Data was collected from Iran Primer, Atlantic Council, U.S. Department of State, Federal Register, U.S, Department of the Treasury, Iran Watch, CSIS, Kharon, Brookings, Center on Global Energy Policy, Holland & Knight, White House Fact Sheets, and Voice of America.
Note: The above table represents the most relevant economic restrictions targeting Iran's UAV sector. For a more exhaustive list of policies, see: "Timeline of U.S. Sanctions," The Iran Primer (February 24, 2025). https://iranprimer.usip.org/resource/timeline-us-sanctions. Accessed October 14, 2025; and Ashish Kumar Sen, "A Brief History of Sanctions on Iran," Atlantic Council (May 8, 2018). https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 14, 2025.

The first U.S. policies targeting Iran's economy came directly after the 1979 Islamic Revolution and the subsequent hostage crisis where Iranian students held American diplomats captive in the U.S. embassy in Tehran. The policies were intended to pressure the Iranian government to release the American hostages, with U.S. exports to Iran falling from $3.7 billion to $23 million in 1980.[221] The decision marked the start of a long-held U.S. strategy of economic restriction, which has remained the cornerstone of U.S.-Iran relations.

In the 1980s, the newly formed Islamic Republic of Iran's hostile attitude towards the West, bolstered by ties to emerging militant movements including Hezbollah, Hamas, Palestinian Islamic Jihad, and the Houthis, deepened U.S. fears of weapons of mass destruction (WMD) proliferation. The United States joined the Missile Technology Control Regime (MTCR) and, several years later, the Wassenaar Arrangement, to prevent such proliferation of missiles, conventional arms, and dual-use technologies to adversaries and their proxies. To strengthen the policy regime, the United States began initiating secondary sanctions on Iran during the 21st century. By using its

[218] Ryan Bacic, "US Expands Export Controls With Long-Awaited '50% Rule' – Here's What to Know," Kharon (September 29, 2025), https://www.kharon.com/brief/bis-50-percent-rule-entity-list-meu-export-controls. Accessed October 15, 2025.
[219] Bureau of Industry and Security, "One Year Suspension of Expansion of End-User Controls for Affiliates of Certain Listed Entities," Federal Register (November 12, 2025), https://www.federalregister.gov/documents/2025/11/12/2025-19846/one-year-suspension-of-expansion-of-end-user-controls-for-affiliates-of-certain-listed-entities. Accessed November 12, 2025.
[220] Ryan Bacic, "US Expands Export Controls With Long-Awaited '50% Rule' – Here's What to Know," Kharon (September 29, 2025), https://www.kharon.com/brief/bis-50-percent-rule-entity-list-meu-export-controls. Accessed October 15, 2025.
[221] Kate Hewitt and Richard Nephew, "How the Iran hostage crisis shaped the US approach to sanctions," Brookings (March 12, 2019), https://www.brookings.edu/articles/how-the-iran-hostage-crisis-shaped-the-us-approach-to-sanctions/. Accessed October 23, 2025.

international dominance in global banking, the United States compelled foreign banks and organizations to withdraw from the Iranian economy.[222]

During the Obama Administration, the United States pursued a "dual-track strategy" towards Iran, leveraging economic restrictions to pressure Iran to diplomatically engage with the United States.[223] In 2015, the United States brokered the Joint Comprehensive Plan of Action (JCPOA), a landmark deal between Iran and the P5+1 (United Nations Security Council Permanent Members and Germany), which provided sanctions relief in exchange for assurances of a peaceful Iranian nuclear program.[224] In 2018, President Trump withdrew from the deal, reimposing the economic restrictions that were waived under the agreement.[225]

While the previous restrictions indirectly impacted Iran's drone industry, the 2021 U.S. sanctions targeting entities and individuals supporting the Islamic Revolutionary Guard Corps' (IRGC) UAV program marked the first U.S. policies specifically targeting UAV acquisition.[226] Similarly, in 2023, BIS also expanded EAR to include entities related to Iran's UAV programs. The FDPR increased the enforcement, putting restrictions not only on final goods, but also on the intermediary goods created with U.S. technology outside of the United States. Policies in the 2020s broadened the individuals, entities, and materials governed by U.S. restrictions.

Were U.S. policies effective?

U.S. sanctions and export controls targeting Iran's UAS and proliferation programs yielded mixed results. Measures that combined financial isolation with targeted restrictions on dual-use goods were most effective in slowing Iranian access to high-end components necessary for advanced drone development. However, because of the relevance and widespread availability of commercial off-the-shelf (COTS) components in drone production, many policies proved only partially effective. Iran's mature domestic drone industry, bolstered by successful reverse engineering and a network of front companies and transshipment hubs, enables Iran to continue sourcing and reproducing

[222] "Brief History of US Sanctions on Iran," Center on Global Energy Policy (July 21, 2017), https://www.energypolicy.columbia.edu/publications/brief-history-us-sanctions-iran/. Accessed November 3, 2025.
[223] Jonathan M. Epstein, "The U.S. Dual-Track Strategy of Economic Sanctions and Engagement With Iran: Recent Developments and Potential Impact on Foreign Businesses," Holland & Knight (November 3, 2009), https://www.hklaw.com/en/insights/publications/2009/11/the-us-dualtrack-strategy-of-economic-sanctions. Accessed October 16, 2025.
[224] "Joint Comprehensive Plan of Action," U.S. Department of State, https://2009-2017.state.gov/e/eb/tfs/spi/iran/jcpoa/. Accessed October 16, 2025.
[225] "President Donald J. Trump is Ending United States Participation in an Unacceptable Iran Deal," White House Fact Sheet (May 8, 2018), https://trumpwhitehouse.archives.gov/briefings-statements/president-donald-j-trump-ending-united-states-participation-unacceptable-iran-deal/. Accessed October 16, 2025.
[226] "U.S. Sanctions Individuals, Firms for Supporting Iran's Drone Program," Voice of America (October 29, 2021), https://www.voanews.com/a/us-sanctions-individuals-and-companies-for-supporting-iran-s-drone-program/6291132.html. Accessed October 23, 2025.

UAVs.[227] The table below outlines whether key U.S. restrictions were effective in achieving their intended impact. Effectiveness is assessed based on how these policies, together with prior measures, limit the sustained technological acquisition of UAVs and related goods.

Table 6: Effectiveness of U.S. Restrictions on Iran

Policy/Instrument	Year Enacted	Intended Impact Achieved?	Explanation of Impact
United States bans Iranian exports to the United States and freezes $12 billion in Iranian assets[228]	November 1979	Partially Achieved	Disrupted immediate access to U.S. markets but allowed for circumvention[229]
U.S. Department of State designates Iran a state sponsor of terrorism[230]	January 1984	Significantly Achieved	Isolated Iran diplomatically and economically[231]
Iran-Iraq Arms Nonproliferation Act opposes the transfer of any goods or technology related to weapons of mass destruction (WMD) to Iran or Iraq[232]	October 1992	Partially Achieved	Strengthened legal barriers on WMD-related exports but had limited enforcement, minimal impact of indigenous production[233]
Executive Order 13224 freezes the assets of foreign terrorists/terrorist entities and associated individuals/entities[234]	September 2001	Partially Achieved	Effectively targeted terrorist financing networks, IRGC and proxies pursued alternative financial channels[235]

[227] "The Private Companies Propelling Iran's Drone Industry," Iran Watch (November 29, 2023), https://www.iranwatch.org/our-publications/articles-reports/private-companies-propelling-irans-drone-industry. Accessed October 24, 2025.
[228] Ibid.
[229] Ashish Kumar Sen, "A Brief History of Sanctions on Iran," Atlantic Council (May 8, 2018), https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 15, 2025.
[230] Ibid.
[231] Ibid.
[232] " Timeline of U.S. Sanctions," *The Iran Primer* (February 24, 2025), https://iranprimer.usip.org/resource/timeline-us-sanctions. On October 14, 2025; Ashish Kumar Sen, "A Brief History of Sanctions on Iran," Atlantic Council (May 8, 2018), https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 14, 2025.
[233] Ashish Kumar Sen, "A Brief History of Sanctions on Iran," Atlantic Council (May 8, 2018), https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 15, 2025.
[234] "Executive Order 13224," *U.S. Department of State*, https://www.state.gov/executive-order-13224. Accessed October 15, 2025.
[235] "Timeline of U.S. Sanctions," *The Iran Primer* (February 24, 2025), https://iranprimer.usip.org/resource/timeline-us-sanctions. On October 14, 2025; Ashish Kumar Sen, "A Brief History of Sanctions on Iran," Atlantic Council (May 8, 2018), https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 14, 2025.

Executive Order 13382 freezes the assets of individuals and entities involved in the proliferation of CBRNs and related good and associated individuals/entities[236]	July 2005	Significantly Achieved	Effectively targeted proliferation networks, restricted transfers related to CBRN and UAV development[237]
Executive Orders 13553, 13574, 13590, 13599, 13606, 13608 and 13645 expand U.S. sanctions by blocking assets, restricting trade and financial transactions, and targeting individuals and entities which support Iranian activities[238]	July 2005, September 2010, May 2011, November 2011, February 2012, April 2012, May 2012, June 2013	Significantly Achieved	Expanded sanctions across sectors; isolated Iranian banking, shipping, and manufacturing sectors[239]
Executive Order 13871 blocked transactions with Iranian iron, steel, aluminum, and copper sectors[240]	May 2018	Partially Achieved	Targeted metals industries, prompted Iranian diversification of export routes and intermediaries[241]
Executive Order 13949 authorized secondary sanctions on entities supporting Iran's conventional arms programs[242]	September 2020	Not Achieved	Lacked international enforcement; Iran continued arms exports to proxies and Russia[243]

[236] "Blocking Property of Weapons of Mass Destruction Proliferators and Their Supports," Federal Register (July 1, 2005), https://www.federalregister.gov/documents/2005/07/01/05-13214/blocking-property-of-weapons-of-mass-destruction-proliferators-and-their-supporters. Accessed October 15, 2025.
[237] Ibid.
[238] "Timeline of U.S. Sanctions," The Iran Primer (February 24, 2025), https://iranprimer.usip.org/resource/timeline-us-sanctions.
[239] Ibid.
[240] Ibid.
[241] Emma Helfrich, "Iranian Mohajer-6 Drones Used by Russia Loaded With Western Parts," The War Zone (November 16, 2022), https://www.twz.com/iranian-mohajer-6-drones-used-by-russia-loaded-with-western-parts. Accessed September 10, 2025
[242] Industry and Security Bureau, "Export Control Measures Under the Export Administrations Regulations (EAR) To Address Iranian Unmanned Aerial Vehicles (UAVs) and Their Use by the Russian Federation Against Ukraine," Federal Register (February 27, 2023), https://www.federalregister.gov/documents/2023/02/27/2023-03930/export-control-measures-under-the-export-administration-regulations-ear-to-address-iranian-unmanned. Accessed October 15, 2025.
[243] Ibid.

OFAC announces sanctions targeting individuals and entities involved with IRGCs UAV program[244]	October 2021	Partially Achieved	Restricts individuals directly related to IRGC's UAV development but does not restrict third party intermediaries[245]
BIS expands EAR to address Iranian UAVs and their use by Russia in Ukraine[246]	February 2023	Partially Achieved	Strengthened controls on UAV components; Iranian and Russian networks sourced dual-use parts via third countries[247]
OFAC publishes "Guidance to Industry on Iran's UAV-Related Activities"[248]	June 2023	Significantly Achieved	Enabled industry to understand the significance of low-level components in drone production[249]
BIS issues the Iran Foreign Direct Product Rule, restricting the exports of U.S.-origin goods to Iran[250]	April 2024	Partially Achieved	Limited direct access to U.S.-origin technology; Iranian drones utilize commercial off-the-shelf components[251]
OFAC expands sanctions to include entities involved in Iran's UAV program[252]	April 2024	Partially Achieved	Targeted UAV producers and front companies; drone exports to Russia and proxies continue[253]

[244] "U.S. issues Iran-related sanctions over drone program," Reuters (October 29, 2021), https://www.reuters.com/world/middle-east/us-issues-new-iran-related-sanctions-treasury-website-2021-10-29/. Accessed October 16, 2025; Office of Foreign Assets Control, "Counter Terrorism Designations and Designation Update; Iran-related Designations; Non-Proliferation Designations," U.S. Department of the Treasury (October 29, 2021), https://ofac.treasury.gov/recent-actions/20211029. Accessed October 16, 2025.
[245] Ibid.
[246] Industry and Security Bureau, "Export Control Measures Under the Export Administration Regulations (EAR) To Address Iranian Unmanned Aerial Vehicles (UAVs) and Their Use by the Russian Federation Against Ukraine," Federal Register (February 27, 2023), https://www.federalregister.gov/documents/2023/02/27/2023-03930/export-control-measures-under-the-export-administration-regulations-ear-to-address-iranian-unmanned. Accessed November 26, 2025.
[247] "U.S. Sanctions Network Supplying Iran's Missile & Drone Programs," Iran Primer (February 2, 2024), https://iranprimer.usip.org/blog/2024/feb/02/us-sanctions-network-supplying-iran%E2%80%99s-missile-drone-programs. Accessed November 26, 2025.
[248] Office of Foreign Assets Control, "Guidance to Industry on Iran's UAV-Related Activities," U.S. Department of the Treasury (June 9, 2023), Guidance to Industry on Iran's UAV-Related ActivitiesOffice of Foreign Assets Control (.gov)https://ofac.treasury.gov › recent-actions › 20230609. Accessed November 26, 2025.,
[249] Ibid.
[250] Industry and Security Bureau, "Iran Foreign Direct Product Rule," Federal Register (July 26, 2024), Iran Foreign Direct Product RuleFederal Register (.gov)https://www.federalregister.gov › 2024-16566 › iran-fo.... Accessed November 26, 2025.
[251] Ibid.
[252] Office of Foreign Assets Control, "Iran Sanctions," U.S. Department of the Treasury, https://ofac.treasury.gov/sanctions-programs-and-country-information/iran-sanctions. Accessed October 15, 2025.
[253] "The Convergence and Evolution of Two Networks Supplying Iran's UAV Program," Iran Watch (July 29, 2024), https://www.iranwatch.org/our-publications/international-enforcement-actions/convergence-evolution-two-networks-supplying-irans-uav-program. Accessed November 26, 2025.

OFAC designates five individuals/entities in Iran, Hong Kong, Taiwan, and China for supporting HESA's procurement[254]	July 2025	Significantly Achieved	Prohibited individuals and entities from directly purchasing from U.S. firms[255]
Reinterpretation of MTCR for UAS Exports, classifying UAS as military aircraft instead of missiles[256]	September 2025	Not Achieved	Intended to control for UAS proliferation, but reclassification could facilitate broader exports[257]
BIS issues the "50% Rule" which expands end-use controls to any entities that are majority owned by parties on the entity list[258]	September 2025 – November 2025[259]	Partially Achieved	Closed loophole by extending controls to majority-owned subsidiaries; improved enforcement against shell networks however enforcement was suspended[260]
BIS adds Chinese, Hong-Kong, and Turkish entities to the Entities List for their role in facilitating unmanned aircraft procurement networks in Iran[261]	October 2025	Partially Achieved	Disrupted UAV procurement networks, did not eliminate alternate supply chains[262]

Sources: For links to the source materials, please see in-text footnotes. Data was collected from Iran Primer, Atlantic Council, U.S. Department of State, Federal Register, U.S, Department of the Treasury, Iran Watch, CSIS, Kharon, Brookings, Center on Global Energy Policy, Holland & Knight, White House Fact Sheets, and Voice of America.
Note: The above table represents the most relevant economic restrictions targeting Iran's UAV sector. For a more exhaustive list of policies, see: "Timeline of U.S. Sanctions," The Iran Primer *(*February 24, 2025). https://iranprimer.usip.org/resource/timeline-us-sanctions. Accessed October 14, 2025; and Ashish Kumar Sen, "A Brief

[254] "Treasury Sanctions Global Network Supporting Iran's Military UAV Program," Iran Watch (July 31, 2025), https://www.iranwatch.org/library/governments/united-states/executive-branch/department-treasury/treasury-sanctions-global-network-supporting-irans-military-uav-program. Accessed October 16, 2025.
[255] Ibid.
[256] Tom Karako, "A Marie Kondo Moment for MTCR: Tidying Up the U.S. Approach to Missile Proliferation," Center for Strategic and International Studies (September 23, 2025), https://www.csis.org/analysis/marie-kondo-moment-mtcr. Accessed October 15, 2025.
[257] Tom Karako, "A Marie Kondo Moment for MTCR: Tidying Up the U.S. Approach to Missile Proliferation," Center for Strategic and International Studies (September 23, 2025), https://www.csis.org/analysis/marie-kondo-moment-mtcr. Accessed October 15, 2025.
[258] Ryan Bacic, "US Expands Export Controls With Long-Awaited '50% Rule' – Here's What to Know," Kharon (September 29, 2025), https://www.kharon.com/brief/bis-50-percent-rule-entity-list-meu-export-controls. Accessed October 15, 2025.
[259] Bureau of Industry and Security, "One Year Suspension of Expansion of End-User Controls for Affiliates of Certain Listed Entities," Federal Register (November 12, 2025), https://www.federalregister.gov/documents/2025/11/12/2025-19846/one-year-suspension-of-expansion-of-end-user-controls-for-affiliates-of-certain-listed-entities. Accessed November 12, 2025.
[260] Alison J. Stafford Powell et al., "BIS Introduces New "Affiliate Rule" Significantly Expanding Entity List, MEU List, and SDN End User Licensing Requirements Under the Export Administration Regulations," Global Sanctions and Export Control Blog (October 2, 2025), https://sanctionsnews.bakermckenzie.com/bis-introduces-new-affiliates-rule-significantly-expanding-entity-list-meu-list-and-sdn-end-user-licensing-requirements-under-the-export-administration-regulations/. Accessed December 12, 2025.
[261] Ibid.
[262] Janatan Sayeh "U.S. Sanctions China-Based Front Companies Procuring Drone Components for Iran," Foundation for Defense of Democracies (March 3, 2025), https://www.fdd.org/analysis/policy_briefs/2025/03/03/u-s-sanctions-china-based-front-companies-procuring-drone-components-for-iran/. Accessed October 16, 2025.

History of Sanctions on Iran," Atlantic Council (May 8, 2018). https://www.atlanticcouncil.org/blogs/new-atlanticist/a-brief-history-of-sanctions-on-iran/. Accessed October 14, 2025.

The policies that significantly achieved their intended impact, including several executive orders, the 50% rule, and increased entities list designation, leveraged U.S. dominance in global finance and global supply chains to disrupt procurement channels and constrain the Islamic Republic's access to precision components such as navigation systems, microprocessors, radio-frequency modules, composite materials, and engine turbines.[263] Additionally, OFAC's "Guidance to Industry on Iran's UAV-Related Activities," better prepared industry counterparts to enforce U.S. export control laws, placing emphasis on existing restrictions and penalties.

Several U.S. sanctions and export control measures achieved partial effectiveness in limiting Iran's UAV acquisition by disrupting some procurement channels but failed to address all circumvention pathways. For example, in 2024, Ukrainian forces recovered a Mohajer-6 drone near Kursk containing Western-made components: microchips from Linear Technology Corporation; an engine from a Canadian Bombardier subsidiary; a servomotor from Japan's Tonegawa-Seiko; and a voltage step-down from Texas Instruments.[264] Approximately 75% of the drone's components originated from Western manufacturers.[265] Iran adapted by exploiting gaps in enforcement, relying on networks in Turkey, the UAE, and Malaysia to reexport components originally manufactured in Europe or East Asia.[266]

Some U.S. policies did not achieve their intended impact on Iran's UAV acquisition due to weak enforcement and gaps in multilateral coordination. In September 2025, the Trump administration announced a reinterpretation of the MTCR, which classifies UASs as analogous to aircraft, rather than to missiles. While the change was intended to facilitate the transfer of unmanned aircraft to U.S. allies and partners, it also removed UAVs from MTCR's governance, making components more

[263] "Guidance to Industry on Iran's UAV-Related Activities," Office of Foreign Assets Control (June 9, 2023), https://ofac.treasury.gov/recent-actions/20230609. Accessed October 24, 2025.
[264] Emma Helfrich, "Iranian Mohajer-6 Drones Used by Russia Loaded With Western Parts," The War Zone (November 16, 2022), https://www.twz.com/iranian-mohajer-6-drones-used-by-russia-loaded-with-western-parts. Accessed September 10, 2025; David Albright, Sarah Burkhard, and Spencer Faragasso, "Iranian Drones in Ukraine Contain Western Brand Components," Institute for Science and International Security (October 31, 2022), https://isis-online.org/isis-reports/iranian-drones-in-ukraine-contain-western-brand-components. Accessed October 16, 2025.
[265] Ian Talley, "Ukrainian Analysis Identifies Western Supply Chain Behind Iran's Drones," The Wall Street Journal (November 16, 2022), https://www.wsj.com/articles/ukrainian-analysis-identifies-western-supply-chain-behind-irans-drones-11668575332. Accessed October 17, 2025; Natalie Sedletska, Maksym Savchuk, Kyrylo Osyaniy and Carl Schreck, "How Western Tech In Iranian Drones Is Helping Russia Wage War On Ukraine," Radio Free Europe Radio Liberty (November 4, 2022), https://www.rferl.org/a/ukraine-russia-drones-iran-western-technology/32115733.html. Accessed October 16, 2025.
[266] Janatan Sayeh "U.S. Sanctions China-Based Front Companies Procuring Drone Components for Iran," Foundation for Defense of Democracies (March 3, 2025), https://www.fdd.org/analysis/policy_briefs/2025/03/03/u-s-sanctions-china-based-front-companies-procuring-drone-components-for-iran/. Accessed October 16, 2025.

easily accessible.[267] Additionally, EO13949, authorized in September 2020, sought to limit Iran's conventional arms transfers. However, it did not prevent the continued supply of drones to Russia and militant proxies because it lacked international enforcement, particularly with China and Turkey, allowing intermediaries to continue supplying components to industry.[268] In addition, after Pishtazan Kavosh Gostar Boshra (PKGB) and its subsidiary Narin Sephehr Mobin Isatis (NSMI) were sanctioned by the United States in February 2024, the companies facilitated the purchase and shipment of key UAV components via intermediary procurement firms abroad—Dingtai Industrial Technology Co., Yonghongan Trade Limited, and Duling Technology Limited.[269] According to a U.S. Treasury press release from February 2025, Iranian firms were able to use these fronts to acquire valve assemblies, radio-frequency connectors, engines, vane turbines, blade turbines, and vane compressors.[270]

All regulations, to some degree, remain susceptible to smuggling. Like that of semiconductors, UAV components are small and easily obfuscated across borders. However, unlike semiconductors, UAV components are widely available on the commercial market.[271] For example, the Texas Instrument's voltage regulator, found in the Mohajer-6, can be used in consumer electronics, medical devices, and LED lighting. The dual-use nature of UAS components makes enforcement exceedingly difficult. Supply side controls have inherent limits because widely available commercial parts are difficult to control.[272]

More enduring than the smuggling issue, evidence of reverse-engineering indicates that Iran has learned from foreign design and has increased its production capacity. Even with limited access to Western-made designs, Iranian engineers can reverse-engineer and scale for production unlicensed copies of drone components. For example, the Shahed-136 uses a design borrowed from the German LimbachL550E aircraft engine, and the Shahed-191 uses a Tolou-10 turbojet

[267] Tom Karako, "A Marie Kondo Moment for MTCR: Tidying Up the U.S. Approach to Missile Proliferation," Center for Strategic and International Studies (September 23, 2025), https://www.csis.org/analysis/marie-kondo-moment-mtcr. Accessed October 15, 2025.
[268] "The Convergence and Evolution of Two Networks Supplying Iran's UAV Program," Iran Watch (July 29, 2024), https://www.iranwatch.org/our-publications/international-enforcement-actions/convergence-evolution-two-networks-supplying-irans-uav-program. Accessed November 26, 2025.
[269] "U.S. Sanctions Network Supplying Iran's Missile & Drone Programs," Iran Primer (February 2, 2024), https://iranprimer.usip.org/blog/2024/feb/02/us-sanctions-network-supplying-iran%E2%80%99s-missile-drone-programs. Accessed November 26, 2025.
[270] "Treasury Targets Covert Iranian UAV Procurement Network," U.S. Department of the Treasury (February 26, 2025), https://home.treasury.gov/news/press-releases/sb0031. Accessed October 21, 2025; "Treasury Targets Covert Iranian UAV Procurement Network," Iran Watch (February 26, 2025), https://www.iranwatch.org/library/governments/united-states/executive-branch/department-treasury/treasury-targets-covert-iranian-uav-procurement-network. Accessed October 16, 2025; Janatan Sayeh "U.S. Sanctions China-Based Front Companies Procuring Drone Components for Iran," Foundation for Defense of Democracies (March 3, 2025), https://www.fdd.org/analysis/policy_briefs/2025/03/03/u-s-sanctions-china-based-front-companies-procuring-drone-components-for-iran/. Accessed October 16, 2025.
[271] Uzi Rubim, "Russia's Iranian-Made UAVs: A Technical Profile," RUSI (January 13, 2023), https://www.rusi.org/explore-our-research/publications/commentary/russias-iranian-made-uavs-technical-profile. Accessed October 24, 2025.
[272] Natalie Sedletska et al., "How Western Tech In Iranian Drones Is Helping Russia Wage War On Ukraine," Radio Free Europe Radio Liberty (November 4, 2022), https://www.rferl.org/amp/ukraine-russia-drones-iran-western-technology/32115733. Accessed October 24, 2025.

engine, a copy of the Czech CBS Velak Bites TJ100.[273] The case of the stealthy Lockheed Martin-manufactured Sentinel RQ-170 presents another infamous example of reverse-engineering. In 2011, after a U.S. RQ-170 UAV strayed from Afghanistan airspace and crash-landed in Iranian territory, the Iranian government suggested that it had produced a copy, the Shahed-171. While experts debate whether the Shahed-171 shares operational similarities to the downed RQ-170, the production of the Shahed-171, Shahed-191, Saegheh-1, and Saegheh-2 reveal significant advancements in stealth, propulsion, and the weaponization of UAS.[274]

Lessons Learned from Iranian UAV Innovation

U.S. policies have proven most effective when:

- disrupting access to advanced technologies with specific military applications
- aligning policy goals with industry interests
- coordinating enforcement with allies, including through multilateral coalitions

U.S. policies have been less effective when:

- targeted technologies are ubiquitous and produced in fragmented supply chains
- targeted countries have existing, mature production lines

U.S. policies targeting Iran's UAV program have proven most effective when coordinated with allies and implemented through international enforcement coalitions. Multilateral interdiction efforts, led by European countries have been successful in curbing smuggling operations, though enforcement in volatile regions like Syria remains challenging.[275] Additionally, educating industry on the existing export restrictions, compliance risk indicators, and associated penalties strengthens collaboration between the public and private sectors. Given that U.S. firms hold minimal commercial interests in Iran, they are comparatively well-incentivized to adhere to U.S. regulatory frameworks.

Unlike the semiconductor supply chain, where chokepoints are concentrated among few firms and technologies, the production of UAVs and their components is highly fragmented and commercially ubiquitous. Most components used in Iranian drones—rotors, sensors, circuits, and engines—are not unique to military applications and are common in civilian goods. Because thousands of firms manufacture such components across the globe, no single company or state maintains monopoly

[273] "Clipping Tehran's Wings: How Supply-Side Controls Can Impede the Iranian Drone Program," Iran Watch (February 15, 2023), https://www.iranwatch.org/our-publications/roundtables/clipping-tehrans-wings-how-supply-side-controls-can-impede-iranian-drone-program. Accessed October 16, 2025.
[274] Sebastien Roblin, "Your Guide to Iran's Diverse Fleet of Combat Drones," National Interest (September 14, 2021), https://nationalinterest.org/blog/buzz/your-guide-irans-diverse-fleet-combat-drones-193654. Accessed October 17, 2025.
[275] New Arab Staff, "Europe dismantles 'Hezbollah drone supply network' spanning four countries," The New Arab (April 13, 2025), https://www.newarab.com/news/europe-dismantles-hezbollah-drone-supply-network-report. Accessed December 10, 2025.

control over UAVs or any of their components. Consequently, U.S. restrictive policies on UAV technologies face greater circumvention challenges.

Ultimately, U.S. policy has succeeded in delaying Iranian qualitative improvements but not its quantitative expansion. The War in Ukraine demonstrates the introduction of newer variants of low-cost, long-range drones. The dual-use nature of UAVs —and of nearly every component that constitutes them—means that broad-based sanctions and export controls are limited in their effectiveness. While the United States has effectively hindered the acquisition of advanced drones, Iran's drone acquisition at large remains unharmed.

Key Takeaways and Conclusion

Table 7 below summarizes lessons learned from restrictive economic policies in the three presented cases. The findings from each case study are distilled into four key characteristics that influence policy effectiveness: partnerships and coordination, types of goods targeted, supply chain characteristics, and approaches to circumvention and adaptability. Partnerships and coordination refer to the presence, or lack thereof, of collaboration and alignment among the United States, allies, and industry partners. The type of goods targeted may refer to a final good, intermediate good, inputs of final goods, or machinery used in production. These characteristics are related to, but distinct, from supply chain characteristics, which denotes the distribution and concentration of production processes. Circumvention strategies refer to the ability of states to exploit gaps in policy to either bypass U.S. restrictions or to innovate in the face of them.

Table 7: Patterns of Effective Restrictive Economic Policies

Attributes of Policies	**Lessons Learned from Effective Policies**
Partnerships and Coordination	1) Policies pursued in coordination with allies and industry are more effective in restricting access to targeted goods. Multilateral policies help prevent circumvention. Policies can be coordinated with allies, partners, and industry firms by implementing the following methods: • Implementing and enforcing policies with allies and partners • Providing guidance to industry on best practices for enforcement • Coordinating enforcement with industry partners
Types of Goods Targeted	1) Policies restricting high-complexity, low-substitutability goods are more effective because they are less accessible. 2) Policies restricting key inputs, intermediate goods, and specialized machinery are more effective than policies only restricting final goods because they disrupt production lines. 3) Policies targeting goods that require large-scale infrastructure (like ice-class LNG carriers) are more effective because they are easiest to monitor and enforce and are less susceptible to smuggling. 4) Policies targeting goods that require mass production for sustained capability (like semiconductors, which necessitate large-scale access to power HPC) are more effective because they prevent sustained, meaningful, at-scale production.

	5) Policies targeting goods whose components confer specific military capabilities and that are not dual-use are more effective as these goods are not commercially accessible and are not susceptible to commercial circumvention methods.
Supply Chain Characteristics	1) Policies targeting supply chain chokepoints, where production is concentrated in one or few countries, are more effective because end-use is easier to monitor. 2) Policies targeting supply-chains where the United States and/or its allied hold significant leverage are more effective because there is a lack of third-party countries to receive the good from.
Circumvention Strategies	1) Policies that anticipate and plan for common evasion tactics are more effective because they close many enforcement loopholes.

In sum, the most effective policies in restricting adversary access to targeted technologies are those which target supply chain components where the U.S. has significant leverage. Effective measures are consistently focused on high-complexity inputs, technological chokepoints, and technologies that require significant capital, expertise, or infrastructure to replicate. In each of the above cases, this tactic has limited meaningful acquisition despite attempted circumvention. Such limitations also prevent adversary innovation. U.S. or Western dominance in advanced photolithography and SME (in the case of Chinese semiconductor innovation), advanced maritime and liquefaction technology (in the case of Russian LNG innovation), and advanced navigation and ISR technology (in the case of Iranian UAV innovation) has prevented qualitative advancements to current adversary capabilities.

While economic restrictions are ineffective in completely halting adversary acquisition or innovation, these tools are effective in delaying such innovation, and in delaying or limiting the at-scale production necessary to confer strategic advancements in capabilities. In each of the above cases, adversaries have access to technologically limited versions of targeted goods: legacy chips, non-ice-class LNG carriers, and low-capability drones. U.S. economic restrictions have adeptly limited the acquisition of advanced semiconductors with HPC capabilities, ice-class LNG vessels, and drones with advanced ISR and navigation systems.

Ineffective policies were ones that did not meaningfully address measures mentioned in Table 7. U.S. policies that restricted widely available, low-complexity goods that have both a civilian and military application are unable to prevent adversary acquisition. This is common among goods that have dual-use components. For example, in the case of Iran, components that did not have explicit military application outside of UAV production were widely accessible, rendering technologies technologically limited, though not quantitatively scarce. In these instances, technologies will develop incrementally, despite sustained technological denial. Additionally, uneven enforcement

across allies, partners, and industry, or misaligned incentives across such actors, enables adversary circumvention.

Among all case studies, states adapted through a combination of reverse engineering, shell companies, and alternative procurement pathways, allowing them to sustain or expand production despite sustained technological denial. While policies can be crafted in ways that tighten loopholes, it is unlikely that any policy can prevent circumvention altogether. Additional adversaries and states may pursue alternative circumvention strategies in other cases. Effective U.S. restrictions are those which delay qualitative innovation.

Some advanced technologies are natural targets for U.S. economic restrictions. Goods that contain the attributes listed in Table 7 are easiest to regulate and restrict. In sectors defined by fragmented and commercially ubiquitous components, however, broad sanctions and export controls face greater circumvention and enforcement challenges. In these instances, U.S. policies can restrict advanced versions of a good, but not the foundational technologies themselves. Additionally, U.S. policies are instrumental in delaying adversary progress. U.S. firms must take advantage of this strategic delay by continuing to innovate. Ongoing innovation helps the United States not only to maintain technological leadership and competitiveness in global markets, but also to remain ahead of emerging threats, adapt to changing regulatory environments, and ensure continued economic growth. As the United States and its allies strengthen export control policy, adversaries continue to seek alternative sources or develop indigenous capabilities to circumvent or innovate around restrictions. By maintaining a technological edge, the United States can continue to set the pace for critical sectors, making it more difficult for adversaries to compete. The United States can support national security strategy and strengthen the reliance of critical supply chains by developing next-generation technologies and adapting its policies to address new challenges.

This paper, in examining three case studies, concludes that U.S. policies are effective in both delaying and limiting adversary acquisition and innovation. By tailoring U.S. sustained technological denial according to the qualities common among effective U.S. policies, the United States can better prevent adversary acquisition of critical technologies. More research should be done to further examine how export control policies specifically impact one state's technological acquisition, or to examine how export control policies impact multiple states' access to a specific technology, however, this is outside the scope of this research. These results are generalizable to other cases where technologically capable and scientifically advanced adversaries pursue indigenous innovation. The continued use of export controls, combined with streamlined processes and effective communication and collaboration with industry and allied partners, is essential for maintaining security and technological leadership in an evolving global landscape.