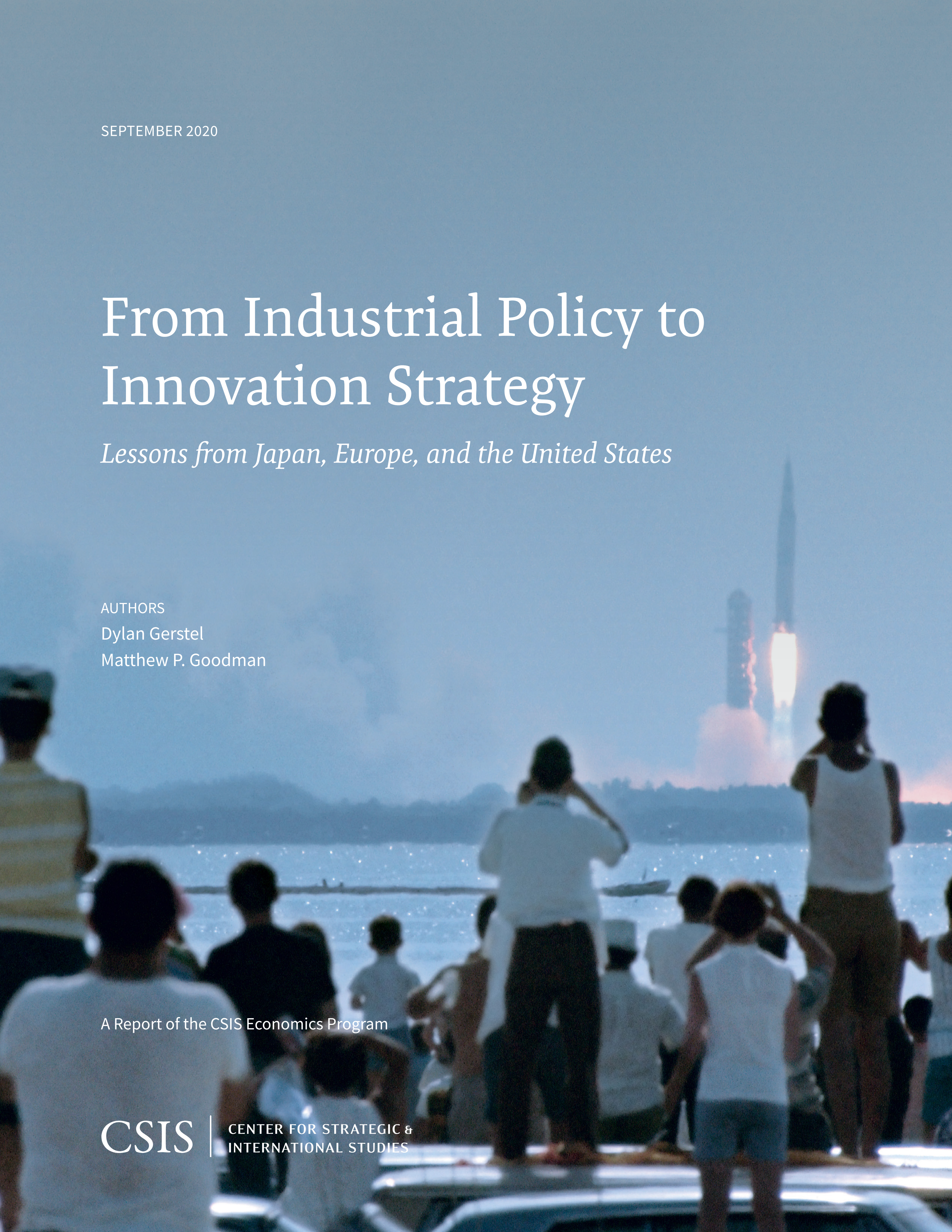

SEPTEMBER 2020

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Executive Summary

All the world's leading economies, including the United States, embrace multiple forms of policies that channel resources towards targeted sectors. Despite distaste for the term in some quarters, elements of industrial policy have always been a significant feature of U.S. policymaking. Since World War II, Washington has used military procurement and large research budgets to accelerate the development of cutting-edge technologies that serve as the foundation of the modern economy, including the Internet, vaccines, satellites, supercomputing, and the components of smartphones.

In response to today's economic challenges—particularly managing the Covid-19 pandemic and the rise of China—prominent U.S. policymakers and political figures on both sides of the aisle, as well as business leaders, have called for more active government efforts to boost domestic production and innovation. However, there is significant disagreement about how to do so.

This report focuses on the role of government in supporting innovation in critical technologies, although there are other challenges—notably Covid-19—where greater federal intervention could be appropriate. To help further the discussion, we reviewed historical approaches to industrial policy in three advanced democracies: Japan, Western Europe, and the United States. Reflecting on those experiences, we present in this report a set of ten "first principles" intended to guide a more active U.S. innovation strategy to reaffirm the country's leadership in critical technologies:

1. **Define a clear mission**
2. **Invest in the foundations of innovative capacity (e.g., infrastructure, education, basic scientific research)**
3. **Support critical technology categories**
4. **Take risks and tolerate failures**
5. **Keep programs flexible**
6. **Use public-private partnerships to develop technology roadmaps, production capabilities, and markets for federally funded research**
7. **Generate demand for early-stage technologies using government procurement power**

8. **Set standards and accelerate regulatory cycles to reduce uncertainty**

9. **Maximize funding transparency to minimize risk of political capture and rent seeking**

10. **Adhere to and enforce international rules**

The choice facing officials today is not a simple binary one between free-market fundamentalism and centrally planned economic activity. Instead, policymakers can learn from the vast experience of the United States and its allies to design new policies that play to our advantages and marshal whole-of-society resources to overcome the challenges of the twenty-first century.

Contents

Introduction

The U.S. economy faces a number of deep-seated challenges, including rising inequality, stagnating growth and productivity, and the specter of climate change. Alongside these structural concerns, China's rapid growth has heightened anxieties about the end of U.S. economic and technological dominance. The Covid-19 pandemic and lockdown measures to contain the disease have caused economic disruption and uncertainty not seen since the Great Depression. In light of these challenges, U.S. economists and policymakers alike wonder whether Washington needs to reconsider the role of the public and private sectors in the economy and, in particular, whether and how government needs to increase its support for U.S. productive and innovative capacity.

Some orthodox economists dismiss calls for more active federal intervention in the economy as "wasteful industrial policy." However, the United States has a long history of shaping markets to support favored industries. In his seminal 1791 *Report on the Subject of Manufactures*, Alexander Hamilton recommended that Congress use "protecting duties" (tariffs) and "pecuniary bounties" (subsidies) to promote infant domestic manufacturing. He concluded, "There is no purpose, to which public money can be more beneficially applied, than to the acquisition of a new and useful branch of industry."[1]

Despite political distaste for the term in some quarters, industrial policy has always been a significant feature of U.S. policymaking. Since World War II, Washington has used military procurement and large research and development (R&D) budgets to accelerate the development of cutting-edge technologies that serve as the foundation of the modern economy, ranging from the Internet, satellites, GPS, aircraft, vaccines, supercomputing, and the components of smartphones. Indeed, initial federal investment and research contracts awarded to Stanford University in the 1950s and 1960s helped build the foundations of Silicon Valley, just as the Apollo and Minuteman programs drove the growth of the semiconductor industry.[2]

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1. Alexander Hamilton, "Report on the Subject of Manufactures," U.S. House of Representatives, December 5, 1791, https://founders.archives.gov/documents/Hamilton/01-10-02-0001-0007.
2. For more information, see Jonathan Gruber and Simon Johnson, *Jump-Starting America: How Breakthrough Science Can Revive Economic Growth and the American Dream* (New York: Public Affairs, 2019) or Margaret O'Mara, *The Code: Silicon Valley and the Remaking of America* (New York: Penguin Press, 2019).

In response to today's economic challenges—particularly managing Covid-19 and the rise of China—prominent U.S. policymakers on both sides of the aisle, as well as business leaders, have called for more active government efforts to boost domestic production and innovation.[3] Both President Trump and former Vice President Biden have vowed to use government authority to accelerate domestic production of medical equipment necessary to contain Covid-19.[4] In his economic plan announced in July 2020, Biden promised $700 billion of new spending through broader "Buy American" procurement and investments in R&D in key technologies.[5] In a December 2019 speech, Republican Senator Marco Rubio cautioned against "the perils of free-market fundamentalism" and called for "revitalizing American industrial policy" to spur activity in strategic sectors.[6] Former Google CEO Eric Schmidt has cautioned that "Americans have put too much faith in the private sector to ensure U.S. global leadership in new technology," calling for more government involvement to compete with China.[7] However, despite the growing calls for Washington to promote innovation more actively, there is significant disagreement about how to do so.

This report focuses on the role of government in supporting innovation in critical technologies, although there are other challenges—notably Covid-19—where greater federal intervention could be appropriate.[8] To help further the discussion, we reviewed historical approaches to industrial policy in three advanced democracies: Japan, Western Europe, and the United States. Reflecting on those experiences, we present in this report a set of "first principles" intended to guide a more active U.S. innovation strategy in order to reaffirm leadership in critical technologies. We conclude that a comprehensive approach is needed, one which refreshes the "triangular alliance" among government, academia, and business that has long driven U.S. technology breakthroughs.

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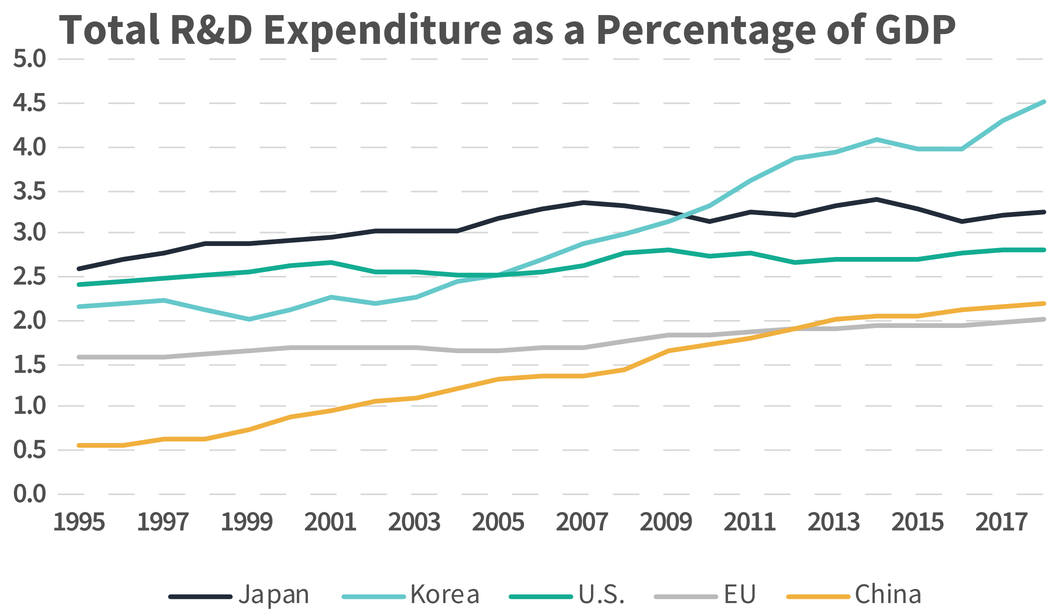
3. U.S. Senate Committee on Small Business & Entrepreneurship, *Made in China 2025 and the Future of American Industry* (Washington, DC: U.S. Senate, February 2019), https://www.rubio.senate.gov/public/_cache/files/d1c6db46-1a68-481a-b96e-356c8100f1b7/3EDECA923DB439A8E884C6229A4C6003.02.12.19-final-sbc-project-mic2025-report.pdf; Jeffrey Mervis, "United States should make a massive investment in AI, top Senate Democrat says," *Science*, November 11, 2019, https://www.sciencemag.org/news/2019/11/united-states-should-make-massive-investment-ai-top-senate-democrat-says; National Security Commission on Artificial Intelligence, *Interim Report*, (Washington, DC: National Security Commission on Artificial Intelligence, November 2019) https://www.epic.org/foia/epic-v-ai-commission/AI-Commission-Interim-Report-Nov-2019.pdf; The Business Roundtable, *Innovation Nation: An American Agenda for Innovation in 2020* (Washington, DC: The Business Roundtable, 2019) https://s3.amazonaws.com/brt.org/BRT-InnovationNationReport.pdf.
4. "Executive Order on Ensuring Essential Medicines, Medical Countermeasures, and Critical Inputs Are Made in the United States," The White House, August 6, 2020, https://www.whitehouse.gov/presidential-actions/executive-order-ensuring-essential-medicines-medical-countermeasures-critical-inputs-made-united-states/; "The Biden Plan to Rebuild U.S. Supply Chains and Ensure the U.S. Does Not Face Future Shortages of Critical Equipment," Biden for President, July 2020, https://joebiden.com/supplychains/.
5. "The Biden Plan to Ensure the Future is 'Made in All of America' by All of America's Workers," Biden for President, July 2020, https://joebiden.com/madeinamerica/.
6. Marco Rubio, "American Industrial Policy and the Rise of China" (speech at National Defense University, December 10, 2019), https://www.rubio.senate.gov/public/_cache/files/5922cc54-2966-48a1-8e88-f7b51bbeca06/D0E7312935012E45F20C67A3450DDAFD.ndu-china-industrial-policy.pdf.
7. Eric Schmidt, "I Used to Run Google. Silicon Valley Could Lose to China," *New York Times*, February 27, 2020, https://www.nytimes.com/2020/02/27/opinion/eric-schmidt-ai-china.html; Eric Schmidt, "Economy Disrupted: Technology, Data, and Innovation Policy" (discussion at the Center for Strategic and International Studies, July 17, 2020), https://www.csis.org/events/online-event-technology-data-and-innovation-policy.
8. For an instructive study on using industrial policy to manage Covid-19, see Reda Cherif and Fuad Hasanov, *A TIP Against the Covid-19 Pandemic (Washington, DC: International Monetary Fund, July 3, 2020),* https://www.imf.org/en/Publications/WP/Issues/2020/07/03/A-TIP-Against-the-COVID-19-Pandemic-49538.



Source: "Main Science and Technology Indicators: Gross Domestic Expenditure on R&D," Organization for Economic Cooperation, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB.

The China Challenge

Chinese President Xi Jinping's turn towards statist economic policies and repressive social control, as well as China's rapid technological advancements, has contributed to a widespread view in Washington that the United States is in strategic competition with China. While technological advancement naturally rises with economic growth, many U.S. observers argue that Beijing has unfairly fueled its development through massive state support and technology acquisition from foreign countries, especially the United States, through both legal and illicit means.[9] There are widespread concerns in the Washington policy community that China's ambition to be a global innovation leader will undermine U.S. competitiveness and national security.

U.S. policymakers and businesses often cite the "Made in China 2025" (MIC2025) plan as emblematic of Beijing's efforts to dominate cutting-edge technologies. While formally disavowed by the Chinese government, MIC2025 is still a *de facto* guide to policy and the centerpiece of a patchwork of state- and local-level programs that make up Beijing's industrial strategy. MIC2025 and other initiatives employ a wide range of tools—including broad government subsidies (including direct grants of support, abundant concessional

9. On industrial subsidies, see U.S. Senate Committee on Small Business & Entrepreneurship, *Made in China 2025 and the Future of American Industry*; For trade barriers, see Robert D. Atkinson, *Enough is Enough: Confronting Chinese Innovation Mercantilism* (Washington, DC: Information Technology & Innovation Foundation, February 28, 2020), https://itif.org/publications/2012/02/28/enough-enough-confronting-chinese-innovation-mercantilism; For tech transfer, see Michael Brown and Pavneet Singh, *China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable A Strategic Competitor to Access the Crown Jewels of U.S. Innovation* (Silicon Valley and Boston: Defense Innovation Unit Experimental, January 2018), https://admin.govexec.com/media/diux_chinatechnologytransferstudy_jan_2018_(1).pdf.

financing, and land grants), state-directed mergers and acquisitions, use of domestic regulations to promote "national champions" at the expense of foreign competitors, forced technology transfer through joint venture requirements, and administrative guidance—to support indigenous innovation.[10]

MIC2025 was inspired by industrial policies in other countries, including Germany's "Industry 4.0" plan for intelligent manufacturing, and it shares many strategic priorities with the U.S. Defense Advanced Research Projects Agency (DARPA).[11] Specifically, MIC2025 calls for upgraded industry across ten sectors: 1) new advanced information technology, 2) automated machine tools and robotics, 3) aerospace and aeronautical equipment, 4) maritime equipment and high-tech shipping, 5) modern rail transport equipment, 6) new-energy vehicles and equipment, 7) power equipment, 8) agricultural equipment, 9) new materials, and 10) bio-pharmaceuticals and advanced medical products.[12]

Despite concerns in Washington, China's industrial strategies and MIC2025 have yielded uneven results. A 2017 CSIS report found that China has "a substantial distance to travel before it approaches the level of innovation found in the world's most advanced economies."[13] Subsequent analysis concludes that while China has succeeded in certain sectors, including new-energy vehicles and internet services, it has made limited progress in others, including semiconductors and commercial aircraft.[14] Nonetheless, Beijing has recently doubled down on efforts to localize production of key technologies, especially semiconductors.[15]

The sophisticated nature of China's integration into the global economy requires a nuanced approach to the China challenge. Recent U.S. responses have been largely defensive and punitive: placing tariffs on Chinese goods, sanctioning Chinese companies, and excluding Chinese researchers. A comprehensive strategy also requires proactive actions to reaffirm U.S. technological leadership.

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10. Scott Kennedy, *The Fat Tech Dragon* (Washington, DC: Center for Strategic and International Studies, August 29, 2017), https://www.csis.org/analysis/fat-tech-dragon.
11. Scott Kennedy, *Made in China 2025* (Washington, DC: Center for Strategic and International Studies, June 1, 2015), https://www.csis.org/analysis/made-china-2025; Defense Advanced Research Projects Agency, *Creating Technology Breakthroughs and New Capabilities for National Security*, (Washington, DC: Defense Advanced Research Projects Agency, 2020), https://www.darpa.mil/attachments/DARPA-2019-framework.pdf.
12. Kennedy, *Made in China 2025*.
13. Scott Kennedy, *China's Uneven High-Tech Drive: Implications for the United States* (Washington, DC: Center for Strategic and International Studies, February 27, 2020), https://www.csis.org/analysis/chinas-uneven-high-tech-drive-implications-united-states; Kennedy, *The Fat Tech Dragon.*
14. Ibid.
15. Yoko Kubota, "China Sets Up New $29 Billion Semiconductor Fund," *Wall Street Journal*, October 25, 2019, https://www.wsj.com/articles/china-sets-up-new-29-billion-semiconductor-fund-11572034480.

Japan: Industrial Policy and the Economic Miracle

In the second half of the twentieth century, Japan experienced unprecedented economic growth, with gross domestic product (GDP) rising from $44 billion in 1960 to $5.45 trillion in 1995, a 123-fold increase.[16] During these "miracle" growth decades, the state often intervened in private markets to direct resources to targeted sectors. Economists have debated the effectiveness of Japan's industrial policy: some argue that state intervention underpinned national competitiveness, others claim that it was inefficient and held back the private sector, while others conclude that it had an insignificant net effect on economic growth but influenced which sectors Japan became dominant in.

Japanese economist Masahiro Okuno-Fujiwara and U.S. economist Laura D'Andrea Tyson identify three phases of Japanese industrial policy in which different tools were used:

- 1945–1960: postwar reconstruction, when officials directly regulated private sector activity through price controls, rations, and priority production for coal and steel;
- 1960–1973: support for strategic industries through "hard" measures like tax advantages, subsidies, preferential financing, and trade protection; and
- 1973–1990s: support for strategic industries through "soft" measures including administrative guidance, state-facilitated industry research coordination associations, and structural adjustment assistance for supply and foreign exchange shocks.[17]

Throughout the postwar period, Tokyo engaged in both strategic and corrective industrial policy to promote the development of targeted sectors and fix market failures, respectively. Japanese officials often targeted industries associated with future productivity growth, such as semiconductors and supercomputers, although they also selected industries to boost employment or based on political motivations. Beginning in the 1970s, developed countries, led by the United States, attacked Japan's industrial policies as protectionist and unfair and took retaliatory measures. Facing external pressure

16. "GDP (current US$) – Japan," World Bank, 2020, https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=JP.
17. Masahiro Okuno-Fujiwara, *Industrial Policy in Japan: A Political Economy View* (Chicago: University of Chicago Press, 1991): 271–304, https://core.ac.uk/download/pdf/6900233.pdf.

and changing market dynamics, Japan liberalized many of its trade, competition, and financial rules and abandoned heavy-handed intervention by the 1990s.

Origins of Japan's Postwar Industrial Planning

In a 1946 report, an advisory committee to the Ministry of Foreign Affairs warned that Japanese companies would be overwhelmed by foreign competitors and proposed public support for heavy industry and manufacturing. Reports like this established the intellectual foundation for the "Japanese-style market system" of the next few decades, which "emphasized building long-running relationships between economic agents."[18] Japan's industrial strategy relied on several key elements: a centralized bank-dominated financial system that offered subsidized lending to favored enterprises, intimate networks among groupings of business conglomerates known as keiretsu (descendants of the zaibatsu in imperial Japan), close coordination between the public and private sectors, and protection of key industries from foreign competition.

Following Japan's impressive growth in the 1960s and 1970s, a leading school of thought emerged that identified government action as instrumental for growth. In *MITI and the Japanese Miracle*, Chalmers Johnson credited the role of the "developmental state," in which bureaucrats from the Ministry of International Trade and Industry (MITI) used a system of deliberation councils, or shingikai, to direct support to favored industries.[19] A 1991 U.S. Office of Technology Assessment report echoed Johnson's view, concluding that "industrial policy has been a key ingredient" in Japan's economic success, especially in capital intensive industries such as steel, automobiles, and semiconductors.[20] Developmental economist Ha-Joon Chang observed that Japanese industries often defied market dynamics that should have precluded their success. For example, automobile companies faced large obstacles including Japan's relatively limited experience with auto manufacturing, its lack of key resources like rubber and oil, and the entrenched dominance of U.S. competitors.[21] Chang remarked that the industry would not be globally competitive without early protection from foreign competition, initial direct and indirect subsidies, and a protected home market that effectively subsidized exports.

As Japan's economy stagnated in the 1990s, some scholars began to argue that growth during the miracle years had occurred despite inefficient industrial policies, which had now become a drag on the economy.[22] Writing in 1991, Okuno-Fujiwara argued that

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18. Shigeru T. Otsubo, *Post-war Development of war of the Japanese Economy* (Nagoya: Nagoya University, 2007), https://www.gsid.nagoya-u.ac.jp/sotsubo/Postwar_Development_of_the_Japanese%20Economy(Otsubo_NagoyaU).pdf.
19. Chalmers A. Johnson, *MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925-1975 (Stanford: Stanford University Press, 1982).*
20. Office of Technology Assessment, *Japanese Industrial Policy: The Postwar Record and the Case of Supercomputers* (Washington, DC: Office of Technology Assessment, 1991), 239, https://www.princeton.edu/~ota/disk1/1991/9112/911208.PDF.
21. Reda Cherif and Fuad Hasanov, *The Return of the Policy That Shall Not Be Named: Principles of Industrial Policy (Washington, DC: International Monetary Fund, March 26, 2019):* 37.
22. For example, see Michael E. Porter, Hirotaka Takeuchi, and Mariko Sakakibara, *Can Japan Compete* (New York: HarperCollins, 2000) and Richard Beason and David E. Weinstein, "Growth, Economies of Scale, and Targeting in Japan (1955–1990)," *Review of Economics and Statistics* 78, no. 2 (1996): 286–95.

business dynamism and "strong entrepreneurial spirits" were the main factors behind economic growth despite bureaucratic attempts to contain them, although he conceded that the state did help coordinate strategic decision-making and knowledge-sharing.[23] Later studies found that industrial policies lowered national income by funneling investment to lower-growth sectors.[24] For example, a 1993 St. Louis Federal Reserve Bank paper observed that when MITI tried to consolidate domestic automobile producers, it actively discouraged Honda, then a smaller company, from expanding its auto business.[25] Skeptics of industrial policy instead attribute Japan's miracle growth to favorable domestic conditions, especially high investment and savings rates.[26] Finally, critics allege that MITI's decision-making process was susceptible to political capture and benefitted firms with insider access.[27]

More recently, scholars have revisited Japanese industrial policy and emphasized the state's effectiveness in strategically coordinating activities of industry and academia.[28] Some repudiate the methodology of earlier econometric studies that found interventions did not increase productivity—in particular, criticizing that older studies do not account for positive social spillover effects through knowledge diffusion. Others emphasize a holistic model of MITI acting alongside the private sector to transform entrepreneurial firms into innovative ones.[29]

Japan's support for the domestic semiconductor industry is emblematic of effective strategic coordination. Japan began producing sophisticated semiconductors in the 1960s but was far behind U.S. industry.[30] To close the gap with foreign competitors, MITI required U.S. companies to enter joint ventures with Japanese companies to sell certain products into Japan. Like Chinese joint venture requirements today, Japanese policy facilitated transfer of technology while protecting the domestic market for national champions.

To further spur development, the Japanese state organized temporary joint research projects and inter-firm coordination, most notably through the Very Large Scale Integration (VLSI) Technology Research Association. Authorized in 1976 for four fiscal years, VLSI brought together five major Japanese technology producers to share know-

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23. Okuno-Fujiwara, *Industrial Policy in Japan: A Political Economy View*.
24. Beason and Weinstein, "Growth, Economies of Scale, and Targeting"; Robert Lawrence and David Weinstein, "Trade and Growth: Import-Led or Export-Led? Evidence from Japan and Korea" (National Bureau of Economic Research, Working Paper 7264, July 1999); Michael E. Porter and Mariko Sakakibara. "Competition in Japan," *Journal of Economic Perspectives* 18, no. 1, (2004): 27–50.
25. In the 1960s, MITI promoted "orderly" domestic competition where firms specialized in different parts of the supply chain, including a failed effort to consolidate the automobile industry into three companies.
26. Paul R. Krugman, "Targeted Industrial Policies: Theory and Evidence," *Industrial Change and Public Policy* (1983):123-155, https://www.kansascityfed.org/publicat/sympos/1983/S83.pdf; Arthur Alexander, "Japan's Industrial Policy for the U.S.? History Repeating Itself" (Presentation at CSIS, Washington, DC, December 12, 2019).
27. Okuno-Fujiwara, *Industrial Policy in Japan*.
28. Mariana Mazzucato, *The Entrepreneurial State: Debunking Public vs. Private Sector Myths* (New York: Public Affairs, 2015): 43–46.
29. Dani Rodrik, "Industrial Policy: Don't Ask Why, Ask How," *Middle East Development Journal* (2008): 1–29, https://drodrik.scholar.harvard.edu/files/dani-rodrik/files/industrial-policy-dont-ask-why-ask-how.pdf; William Lazonick, "Entrepreneurial Ventures and the Developmental State: Lessons from the Advanced Economies," *World Institute for Development Economics Research*, 2008, https://www.econstor.eu/bitstream/10419/84670/1/659519895.pdf.
30. For example, in 1971, Japanese chip makers had to sell at 20 percent below cost to compete with U.S. companies. Office of Technology Assessment, *Japanese Industrial Policy*, 249.

how: Fujitsu, Hitachi, Mitsubishi Electric, Nippon Electric Company, and Toshiba. Tarui Yasuo, who led VLSI from 1976 to 1979, remarked that the program aimed to "reduce duplication of effort" by dividing up labor and avoid patents owned by U.S. firms.[31] MITI supported the VSLI by establishing a cooperative laboratory and extending $116 million in subsidies. [32] VSLI produced more than 1,000 patent applications, especially in integrated circuit technology.[33] By the 1980s, Japanese companies had caught up to U.S. chipmakers in nearly all areas of semiconductor technology, and state intervention, including through VSLI, was recognized as a critical factor behind Japan's success.[34]

Takeaways

During the high-growth era reviewed in this study, Japanese government policies were generally successful in transforming the country's economy and helping domestic companies capture significant market shares of key global industries.[35] Japanese industrial policies were not infallible: some efforts failed out right and others were inefficient, requiring heavy investments over a sustained period of time as well as other supportive policies. However, despite marginal efficiency losses, Japanese policies were effective in helping move the economy up the value chain.

Several observations emerge from Japan's experience:

- **Industrial policy relied on supportive structural features of the Japanese economy.** Without a highly educated workforce, a high savings and investment rate, and the ability to import foreign technology, Japan would not have experienced miracle growth.
- **Clear objectives helped focus development efforts.** Initially, MITI was more geared towards supporting heavy industry and utilities, to mixed effect. In the 1970s, MITI dramatically shifted towards advanced technology manufacturing to compete with the United States and produce critical inputs to other sectors, with greater success.
- **Japan targeted foundational commercial technologies, not defense applications.** In contrast with U.S. and Soviet approaches to foster defense innovation bases, MITI targeted foundational technologies, especially those that were vital inputs for other industries, like steel and semiconductors—due in part to Japan's pacifist constitution. As Japan's policy matured, MITI supported research and development of pre-competitive technologies, including robotics and artificial intelligence, to create a springboard effect for innovation.[36]

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31. Ibid.
32. Kiyonori Sakakibara, "From Imitation to Innovation: The Very Large Scale Integrated (VSLI) Semiconductor Project in Japan," (working paper, MIT Sloan School of Management, October 1983), https://dspace.mit.edu/bitstream/handle/1721.1/47985/fromimitationtoi00saka.pdf?sequence=1.
33. Okuno-Fujiwara, *Industrial Policy in Japan*, 284.
34. Ibid., 300; Office of Technology Assessment, "Japanese Industrial Policy," 249.
35. Robert H. Wade, "The Role of Industrial Policy in Developing Countries," in *Rethinking Development Strategies After the Financial Crisis, United Nations Conference on Trade and Development, October 2015,* 67–79, https://unctad.org/en/PublicationChapters/gdsmdp20151wade_en.pdf.
36. For a partial list of targeted technologies, see Okuno-Fujiwara "Industrial Policy in Japan: A Political Economy View," 299–300.

- **Successful interventions deepened coordination between public and private actors.** Japan's most successful applications of industrial policy set strategic direction and incubated inter-industry linkages to achieve medium-term goals with urgency. These programs incentivized private sector buy-in through recognition of a common industry challenge, public-private co-financing and ownership of research projects, and supportive subsidies available through temporary technology research associations.[37]

- **Successful strategy also required international competition.** Export-oriented companies in Japan were more productive than domestic-oriented firms, because they were forced to out-innovate international competitors and had incentives to learn and adapt foreign technology.[38] Korea and Taiwan employed a similar strategy of emphasizing export sophistication and priority on capturing international markets.[39]

- **Unsuccessful interventions suppressed internal competition.** In certain sectors, MITI used administrative guidance to limit or discourage competition in order to create domestic champions. Business often opposed these efforts, and studies have shown that Japan was most competitive internationally in industries with fierce internal competition, while Japan fell behind in sectors where competition was restricted.[40]

- **MITI's actions faced accusations of political capture and insider bias.** Large, incumbent Japanese firms were said by critics to have received disproportionate support from MITI at the expense of smaller businesses, newer entrants, and foreign firms in the Japanese market.

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37. Technology research associations (TRAs) were made up of several companies and organized to conduct joint research and development with state subsidies. TRAs were organized as temporary entities to solve specific challenges. The VSLI is cited as an example of a successful Japanese TRA.
38. Joe Studwell, *How Asia Works (London: Profile Books, 2013).*
39. Reda Cherif and Fuad Hasanov, "The Leap of the Tiger: Escaping the Middle-income Trap to the Technological Frontier," *International Monetary Fund, July 16, 2019,* https://onlinelibrary.wiley.com/doi/abs/10.1111/1758-5899.12695.
40. Porter and Sakakibara. "Competition in Japan."

Western Europe: Industrial Policy by Other Means

Although Western European economies grew slower than Japan in the postwar period, they still experienced significant growth as they rebuilt from wartime destruction. For example, France's economy grew 25-fold from 1960 to 1995. (By comparison, U.S. GDP grew 14-fold over that period.) However, with a few significant exceptions, Western European countries used fewer "hard" industrial policy instruments—price controls, administrative guidance, trade protection— than Japan in the postwar period.[41] Policymakers, desperate to avoid another continental war, sought to create a single, integrated European market. European Union rules would later ban national tax preferences and other measures that could distort competition in the internal market.[42] Instead, Western European countries pursued industry policy in other ways, including by subsidizing R&D investment, exempting selected technologies from competition rules, and creating demand through regulation, such as with renewable energy.[43]

Today, green goals in Europe often coincide with industrial policies. For example, the European Union's flagship Green Deal effort to achieve no net greenhouse gas emissions by 2050 includes the European Battery Alliance (EBA), which coordinates public and private stakeholders and resources to develop a competitive, EU-wide battery manufacturing value chain.[44] Under the EBA, the European Commission actively encourages industry consortia and partnerships to increase EU global battery market share. At the national level, EU regulations exempt state aid that contributes to an "Important Project of Common European Interest" (IPCEI) from strict competition rules. To qualify as an IPCEI, a project must contribute to strategic EU objectives[45], involve multiple member states, include private

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41. Jacob Kirkegaard, Presentation on Western European Industrial Policy at CSIS, Washington, DC, December 12, 2019.
42. Treaty on the Functioning of the European Union, Article 173, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A12016E173.
43. Facing increasing competition from the United States and China, and pressure from France and Germany, the European Union is reassessing its competition policy and considering allowing the creation of European champions. European Commission, *A New Industrial Strategy for Europe (Brussels: European Commission, March 10, 2020),* https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf.
44. "European Battery Alliance," European Commission, https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en.
45. The EU currently identifies six strategic sectors: connected, clean, and autonomous vehicles; hydrogen technologies and systems; smart heath; industrial internet of things; low-carbon industry; and cybersecurity. "Industrial Policy:

financing, and further an ambitious research agenda. For example, in December 2019 the Commission approved €3.2 billion ($3.6 billion) in direct subsidies from seven member states for battery research and development.[46]

European Commission vice-president Frans Timmermans and EU commissioner for Energy Kadri Simson present a clean hydrogen strategy for Europe on July 8, 2020. Photo by: Virginia Mayo/Pool/AFP via Getty Images

EU-wide Industrial Policy

Article 173 of the Treaty on the Functioning of the European Union bans competition-distorting measures, but it leaves room for "soft" industrial policy, including research support and public-private alliances. At the EU-level, Brussels funds many R&D investment initiatives, including the European Research Council and the Horizon 2020 program, the latter amounting to nearly €80 billion ($90 billion) over seven years—7 percent of the total 2014–2020 EU budget, but small in absolute amounts and widely distributed.[47] In response to competition from China and the United States, the European Commission has proposed wide-ranging tools to counter foreign subsidies and "level the playing field."[48]

Recommendations to Support Europe's Leadership in 6 Strategic Business Areas," European Commission, May 5, 2019, https://ec.europa.eu/growth/content/industrial-policy-recommendations-support-europe%E2%80%99s-leadership-6-strategic-business-areas_en.

46. European Commission, "Commission Approves €3.2 Billion Public Support by Seven Member States for a Pan-European Research and Innovation Project in all Segments of the Battery Value Chain," news release, December 9, 2019, https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6705.

47. European Union, *Integrated Financial Reporting Package: Financial Year 2017*, (Luxembourg: Publications Office of the European Union, 2018), https://ec.europa.eu/budget/library/biblio/media/2017/2017_IFRP_brochure_web_final.pdf.

48. European Commission, *White Paper on Levelling the Playing Field as Regards Foreign Subsidies, (Brussels: European*

We studied three cases of European industrial policy that offer guidance for current U.S. policymakers: the German Fraunhofer manufacturing institutes, Denmark's support for its wind power industry, and attempts to create a European digital search competitor to Google.

FRAUNHOFER: SOCIETAL INNOVATION LINKAGES

Germany has a long history of close public-private sector cooperation, especially in manufacturing. Fraunhofer-Gesellschaft (Fraunhofer Society), a non-profit institute founded in 1949 to support applied research, is emblematic of a wide network of state-organized resources available to companies. (Other institutions, like the Max Planck Society, focus on basic research.)

As of 2019, Fraunhofer was the leading applied research organization in Europe, employing 26,600 people at 72 institutes across Germany with an operating budget of €2.6 billion ($2.9 billion). Fraunhofer gets about a third of its funding from industry contracts, a third from publicly financed research projects, and a third from state and local government "base funding." According to Fraunhofer's 2018 annual report, the large public support enables the institutes to "work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now." [49] Fraunhofer owns 6,881 active patent families, including the mp3 compression algorithm, and consistently ranks as one of the most active filers of intellectual property in Germany.[50]

A former Fraunhofer Executive Director described the organization as a "technology bridge" helping industry translate research into commercial applications, especially for small and medium-sized enterprises (SMEs).[51] Fraunhofer conducts various forms of contract research projects for industry, including joint ventures to scale up new technologies. Thanks to 70 years of close industry collaboration, Fraunhofer functions as the de facto research arm of Germany's Mittelstand, the highly competitive small and medium manufacturers largely responsible for Germany's export success, which often cannot support high-quality in-house research divisions.[52] A recent study of German firms found that larger contracts with Fraunhofer yielded sales and productivity growth.[53] These effects become stronger the more often companies interact with Fraunhofer and are larger for companies generating new technologies than those implementing existing ones.

To engage academia, Fraunhofer supports 17 laboratories where universities and civil society stakeholders can conduct joint research and train new scientists. Fraunhofer also nurtures international collaborations through its 16 affiliate organizations and by working with global industry leaders. For example, in September 2019, Fraunhofer announced a joint project with IBM to install Germany's first commercial quantum computer.[54] Thanks to its success, the Fraunhofer model inspired the Obama

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Commission, June 17, 2020), https://ec.europa.eu/competition/international/overview/foreign_subsidies_white_paper.pdf

49. Fraunhofer-Gesellschaft, *2018 Annual Report* (Munich: Fraunhofer-Gesellschaft, 2018), https://www.fraunhofer.de/content/dam/zv/en/Publications/Annual-Report/2018/Fraunhofer-Annual-Report-2018.pdf.

50. Ibid.

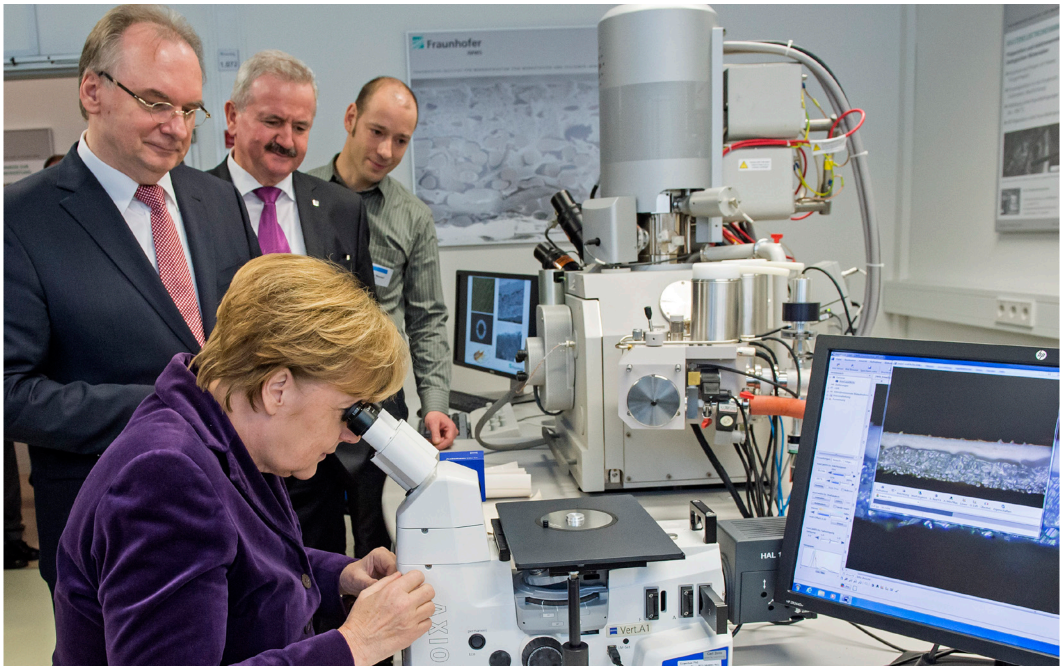
51. Wessner and Wolff, ed., *Rising to the Challenge,* 72.

52. Bernd Venohr and Klaus E. Meyer, *The German Miracle keeps running: How German Hidden Champions Stay Ahead in the Global Economy (Berlin: Berlin School of Economics, May 2007).*

53. Diego Comin, Georg Licht, Maikel Pellens, and Torben Schubert, "Do Companies Benefit From Public Research Organizations? The Impact of the Fraunhofer Society in Germany," *ZEW Discussion Papers 19,* no. 6 (March 2019).

54. "Quantum computing looms large on the horizon," Fraunhofer-Gesellschaft, https://www.fraunhofer.de/en/re-

administration's Manufacturing USA program launched in 2014, which now has 14 applied research institutes across the country.[55]



German chancellor Angela Merkel uses a microscope during the official opening of the Fraunhofer Institute for Microstructure of Materials and Systems. Photo by: Jens Meyer/AFP via Getty Images

Despite its success, the Fraunhofer focus on incremental advances over transformational research may limit its impact. A National Academies of Science study edited by Charles Wessner remarks that while Fraunhofer profits from licensing its mp3 compression algorithm, its transformative applications occurred in industries outside Germany. Nonetheless, the study concludes that "Fraunhofer-Gesellschaft has been a major factor behind Germany's continued export success in advanced industries despite high labor costs."[56]

Denmark: Green Industrial Policy

Entering the 1970s, Denmark relied on oil for approximately 90 percent of its energy, an exceptionally high dependency ratio.[57] After the oil embargo of 1973, the Danish government announced a plan to switch to coal and nuclear power. After the Chernobyl disaster in 1986, under pressure from civil society, the government shifted its emphasis to wind energy. Under the revised plan, the Danish government provided initial support for

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search/current-research/quantum-technologies/quantum-computing.html.

55. "Manufacturing USA," Manufacturing USA, https://www.manufacturingusa.com.
56. Wessner and Wolff, ed., *Rising to the Challenge*, 201–320.

57. United Nations Economic and Social Commission for Asia and the Pacific, *Wind Power Takes Flight in Demark: Denmark's Renewable Energy Policies* (Bangkok: United Nations Economic and Social Commission for Asia and the Pacific, 2012), https://www.unescap.org/sites/default/files/16.%20CS-Denmark-renewable-energy-policies.pdf.

the nascent wind turbine industry, including by establishing a test station, offering research subsidies, and providing capital grants of up to 30 percent to offset installation costs.[58]

Despite state support, by 1989 only a few wind turbines had been built, due to issues with grid connectivity. To generate demand, the government ended capital subsidies and instead implemented a carbon tax and required utilities to connect to turbines and purchase wind power at “fair price” rates of 70–85 percent of local electricity prices.[59] The intervention worked: Denmark’s wind sector experienced rapid growth from 1994–2002, and in 1997 Denmark became a net energy exporter.[60] In 2019, Denmark got 47 percent of its energy from wind power, and today Danish turbine company Vestas and offshore wind farm developer Ørsted are global industry leaders.[61]

Denmark’s Horns Rev wind farm, developed by Danish Energy company Elsam (now Ørsted), was the first large scale offshore wind farm in the world. Photo by: Jorgen True/AFP via Getty Images

58. Jens Vestergaard, Lotte Brandstrup, and Robert D. Goddard III, “Industry Formation and State Intervention: The Case of the Wind Turbine Industry in Denmark and the United States” (Proceedings of the Academy of International Business (Southeast USA Chapter) Conference, November 2004), 329–340, http://www.energybc.ca/cache/denmark-wind/old-hha.asb.dk/man/cmsdocs/publications/windmill_paper2.pdf.
59. Ibid.
60. International Renewable Energy Agency and Global Wind Energy Council, *30 Years of Policies for Wind Energy: Lessons from 12 Wind Energy Markets* (Abu Dhabi: International Renewable Energy Agency, January 2013), https://www.irena.org/documentdownloads/publications/gwec_denmark.pdf.
61. Jacob Gronholt-Pedersen, “Denmark Sources Record 47% of Power From Wind in 2019,” Reuters, January 2, 2020, https://www.reuters.com/article/us-climate-change-denmark-windpower/denmark-sources-record-47-of-power-from-wind-in-2019-idUSKBN1Z10KE.

Observers of Denmark's transition emphasize several factors behind its success. First, there was a stable political coalition to support a long-term strategy favoring wind production. Consistent political will enabled companies to make strategic decisions without worrying about the risk of a new government changing priorities. Second, Danish entrepreneurs in the 1970s realized they could apply their manufacturing techniques and know-how to wind energy. Before it entered the turbine industry, Vestas was a crane producer, and NEG Micon—a former turbine manufacturer acquired by Vestas—made oil tankers.[62] Such relevant expertise gave the industry a head start over foreign competitors and provided an indigenous R&D base for the Danish government to support. Third, the Danish Energy Ministry established a set of quality industry standards that ensured that Danish companies could compete internationally. Finally, and most importantly, the state stimulated lasting demand by legislating that utilities connect wind turbines to national grids and purchase wind energy.[63] Brussels is now seeking to replicate Danish success at the EU-wide level, and the Danish experience informed the European Green Deal plan released in December 2019.[64]

Quaero and Theseus: Europe's Ill-fated Quest to Challenge Google

In April 2005, French President Jacques Chirac and German Chancellor Gerhard Schroeder announced plans for Quaero, a search engine intended to compete with Google. Fearful of the implications of Google's growing dominance in Europe, the two leaders pledged between €1 billion and €2 billion ($1.18 and $2.35 billion) over five years to support the project.[65]

Disputes over the nature of the product (Germany preferred text search, France preferred multimedia search) led Germany to quit Quaero in favor of its own search engine, Theseus. As both projects materialized, officials pared down funding expectations, with the European Union ultimately approving 120 million euros in German aid for Theseus in 2007 and 99 million euros in French aid for Quaero in 2008.[66] Both initiatives brought together several large companies in public-private consortia and pledged to collaborate with the other.[67]

Both programs failed to displace Google and went offline within a few years of their launch. Critics at the time attacked the projects as "vague and unfunded," dismissed them as vanity projects, and predicted their demise.[68] In 2007, Google alone spent $2.1

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62. Vestergaard, Brandstrup, and Goddard III, "Industry Formation and State Intervention."
63. Danish economists have contrasted Denmark's legislated demand model with the U.S. experience of government-sponsored research and subsidies in the 1970s, which failed to generate lasting demand once support was withdrawn in the Reagan administration.
64. European Commission, *A European Green Deal, (Brussels: European Commission, 2020),* https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.
65. Helena Spongenberg, "Germany Ditches France in 'Quaero' Internet Project," EU Observer, January 4, 2007, https://euobserver.com/news/23189.
66. European Commission, "State Aid: Commission Endorses €120 million Aid for German R&D Project THESEUS," news release, July 19, 2007, https://ec.europa.eu/commission/presscorner/detail/en/IP_07_1136; European Commission, "State Aid: Commission Authorises Aid of €99 million to France for QUAERO R&D Programme," news release, March 11, 2008, https://ec.europa.eu/commission/presscorner/detail/en/IP_08_418.
67. Ibid.
68. Philip E. Ross, "What's The Latin for 'Delusional'?" *IEEE Spectrum* 44, no. 1 (2007): 49–50.

billion on R&D, nearly 20 times the amount allocated to the two European projects.[69] Notwithstanding the funding constraints, there were no existing European firms that could compete with Google, and the companies in the Quaero project had little experience with search functions. Despite the program's failure, the European Union has recently launched GAIA-X, an initiative to build a European cloud-service provider beginning with a Franco-German partnership. Skeptics warn that GAIA-X will end the same way that Quaero and Theseus did, because of Amazon and Microsoft's dominant market positions.[70]

Takeaways

In recent decades, strict European competition rules and a shared desire to keep formal trade barriers low precluded most overtly protectionist industrial policy tools in Europe. Instead, as the three case studies above demonstrate, countries used other tools, including R&D subsidies, regulatory instruments, and cooperative business alliances, to stimulate the development of targeted industries. Like in Japan, not all European government-supported initiatives were successful. Some European interventions targeted legacy sectors in order to maintain stable employment, rather than advancing defense or commercial goals, which left Europe unprepared for global competition in emerging technologies.

Several observations emerge from our research:

- **State efforts established deep public-private connections.** Programs like the German Fraunhofer helped closely link the official, private, and academic sectors, thus creating innovation clusters that were especially helpful for SMEs who would otherwise not have access to high-cost equipment and testing services. These connections also helped develop markets for—and speed the adoption of—federally funded research. Replication of the Fraunhofer model in other EU countries has proven challenging, and efforts to do so must take into account characteristics and needs of existing national innovation systems.

- **Successful industry strategy leveraged existing manufacturing know-how.** Bottom-up policies that built on existing manufacturing know-how were more successful than top-down efforts to create a challenger to dominant incumbent firms. States often supported bottom-up innovation by catalyzing research with subsidies and focusing industry direction with national targets.

- **Subsidies alone did not always work; sometimes more active measures were required to generate demand.** Government intervention was required to generate demand for nascent markets. A regulatory approach to industrial policy, such as mandated targets for power use, was effective in correcting negative externalities.

- **Stable political support was essential for industrial policy success.** Political uncertainty complicated private-sector decision making, especially when these

69. Google Inc., *Form 10-K* (Mountain View, CA: Google Inc., February 2008), https://www.sec.gov/Archives/edgar/data/1288776/000119312508032690/d10k.htm.
70. Eline Chivot, "EU is More Than a Decade Late in Its Plan to be a Global Cloud Superpower," Center for Data Innovation, December 12, 2019, https://www.datainnovation.org/2019/12/eu-is-more-than-a-decade-late-in-its-plan-to-be-a-global-cloud-superpower/.

decisions were linked to government policy. Public buy-in helped maintain political consensus for achieving long-term objectives, such as Denmark's transition to wind energy. As a corollary, well-defined projects tackling salient public issues were more successful than those aimed at parochial objectives.

- **Europe had less overt protection than Japan but still favored national firms.** While Europe generally avoided large tariff barriers, industrial and regulatory policy still favored domestic or European companies, often through procurement rules that acted as de-facto barriers to trade. In certain cases, foreign firms could participate in government-supported projects, albeit in a junior role.

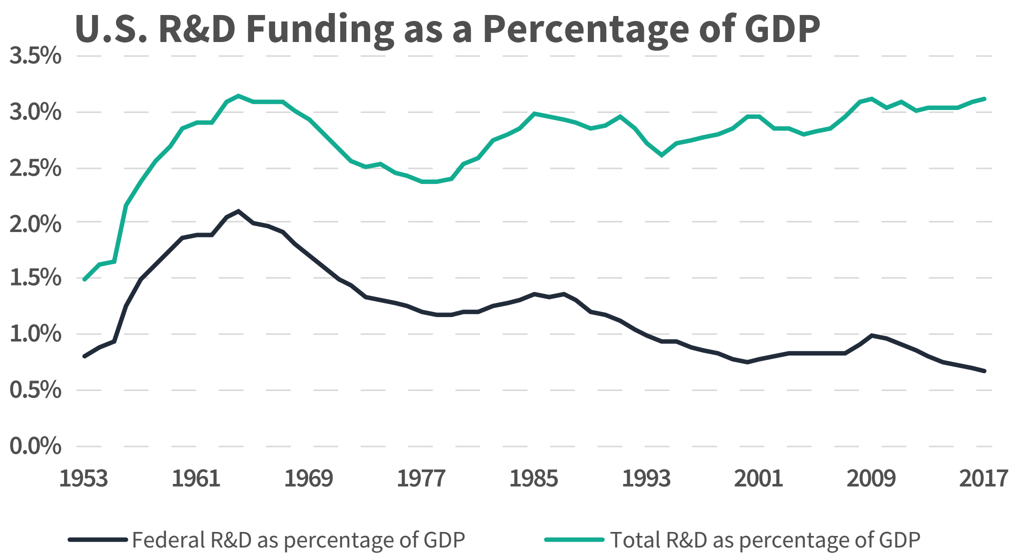
United States: Industrial Policy by Other Names

Although many U.S. politicians bristle at the term "industrial policy," Washington has a long and successful history of supporting selected industries and generously subsidizing technological development with demand- and supply-side activity. The Department of Agriculture—formed in 1862—has helped U.S. farms become some of the most productive in the world. From 1950 to 1980, the U.S. federal government financed between 47 and 66 percent of national R&D spending, compared with approximately 20 percent in Japan and Korea and around 30 percent in Europe over this period.[71] While federal R&D spending in the Cold War era often focused on defense-related research, agencies also supported consumer-facing technology, and many of the defense projects yielded commercial applications.

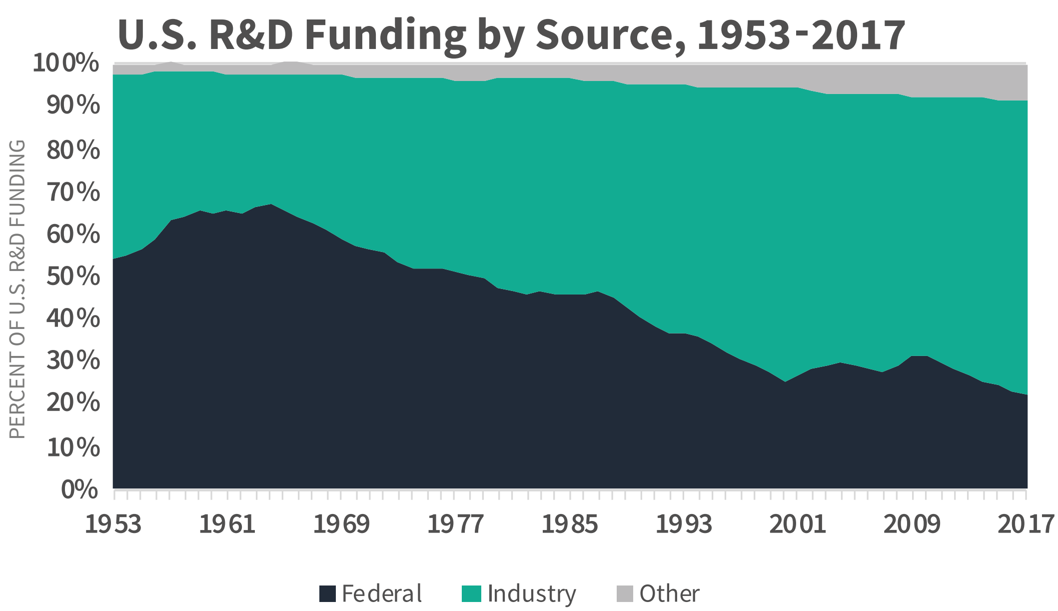
Contemporary U.S. federal efforts to support innovation should build on the successes of prior U.S. industrial policy. Below we study two especially impactful models: the Defense Advanced Research Projects Agency (DARPA) and the Sematech consortium.[72] Both cases offer helpful takeaways for current policymakers seeking to sharpen the U.S. innovative edge.

71. Ha-Joon Chang, "Industrial Policy: Can We Go Beyond an Unproductive Confrontation?" (paper presented at the Annual World Bank Conference on Development Economics, Seoul, South Korea, June 22, 2009), https://hajoonchang.net/wp-content/uploads/2012/01/ABCDE2009-Changpaper.pdf.

72. These two programs are only a subset of public-private cooperation efforts. In addition to DARPA and SEMATECH, the U.S. Small Business Innovation Research (SBIR) program is frequently cited model for federal support.



Source: "Historical Trends in Federal R&D," American Association for the Advancement of Science, https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd.

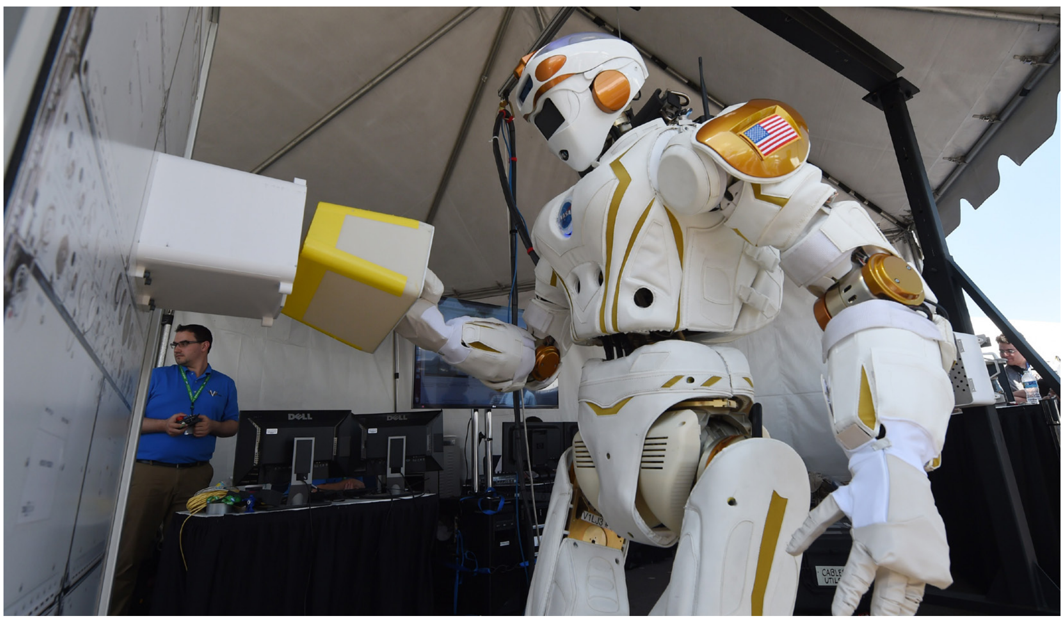


Source: "Historical Trends in Federal R&D," American Association for the Advancement of Science, https://www.aaas.org/programs/r-d-budget-and-policy/historical-trends-federal-rd.

DARPA: Promoting Dual-Use Innovation

The Soviet Union caught the United States and the world by surprise when it successfully launched the first artificial satellite into orbit in 1957. In response, President Eisenhower created the Advanced Research Projects Agency in 1958 ("Defense" was added in 1972) to unify defense-related R&D and to ensure the United States would avoid another "Sputnik moment." The agency was authorized to focus on transformative change rather than incremental advances and had a mission to "prevent and create technological surprise."[73] To achieve its ambitious goals, DARPA invested in basic research and generic technologies with military and commercial potential and cultivated collaborations with academia and industry to identify emerging technological trends.[74]

As DARPA's role expanded, it increasingly focused on foundational research in "dual-use" civilian and military technologies, including artificial intelligence and microelectronics.[75] DARPA-sponsored R&D led to many breakthroughs in military technology, but also to foundational commercial products such as the Internet, global positioning system (GPS), and automated voice recognition.[76] DARPA's accomplishments are even more impressive considering its relatively modest size and budget. In 2019, DARPA employed 220 people, including nearly 100 program managers, to oversee about 250 R&D programs with a budget of $3.4 billion; some have called DARPA "100 geniuses connected by a travel agent."[77]



The humanoid robot 'Valkyrie,' designed by NASA, is displayed at the 2015 DARPA Robotics Challenge, where 24 teams developed robots capable of helping with natural disaster responses. Photo by: Mark Ralston/AFP via Getty Images

73. "About DARPA," Defense Advanced Research Projects Agency, https://www.darpa.mil/about-us/about-darpa; Defense Advanced Research Projects Agency, *Innovation at DARPA* (Arlington: Defense Advanced Research Projects Agency, July 2016), https://www.darpa.mil/attachments/DARPA_Innovation_2016.pdf.
74. Erica R. H. Fuchs, "Rethinking the Role of the State in Technology Development: DARPA and the Case for Embedded Network Governance," *Research Policy* 39, no. 9 (2010): 1133–1146.
75. Marcy Gallo (Presentation on DARPA at CSIS, Washington, DC, January 28, 2020).
76. Congressional Research Service, *Defense Advanced Research Projects Agency: Overview and Issues for Congress* (Washington, D.C.: Congressional Research Service, March 17, 2020), https://fas.org/sgp/crs/natsec/R45088.pdf.
77. "Budget," Defense Advanced Research Projects Agency, https://www.darpa.mil/about-us/budget; William B. Bonvillian, *The Connected Science Model for Innovation - The DARPA Role* (Washington, D.C.: The National Academies Press, 2009), 206–283, https://www.nap.edu/read/12194/chapter/15#223.

Observers attribute DARPA's success to its unique organizational structure, which is flexible, flat, and closely integrated with industry and academia, and which encourages high-risk, mission-driven research.[78]

- *Flexibility and independence:* As head of a federal agency, DARPA's Director has unusual flexibility to move money, being able to transfer funding from one line item to another without needing formal oversight committee approval. DARPA also uses an expedited hiring process outside typical civil-service personnel guidelines.[79] Such flexibility helps keep the organization nimble and responsive to changes in the innovation ecosystem in real time without requiring lengthy approvals. Further, DARPA often receives temporary personnel from other agencies, which builds inter-agency cooperation and gives DARPA the flexibility to invest into or out of scientific fields without adding full-time staff.[80]

- *Flat hierarchy and temporary tenure:* DARPA's flat hierarchical structure reinforces its ability to stay at the technological frontier. Program managers are given sizeable resources and autonomy to pursue projects at their discretion and are not required to abide by peer review panel recommendations.[81] Program managers also have a limited tenure (three to five years), which adds urgency to their projects and gives the Agency opportunities to re-invent itself by bringing in fresh thinking and new ideas.

- *Industry and academia cooperation:* DARPA uses close ties with leading technology companies and academic labs to compensate for its lack of full-time staff. Through these networks, DARPA identifies new technology trends and top research talent and ideas deserving of federal funding. DARPA's short turnover cycle also helps create a dynamic network of creativity between government, business, and academia.

- *High risk tolerance:* DARPA has an ambitious mission of creating transformative technological change. To achieve this goal, program managers subject proposals to a rigorous review and often reject projects deemed to have insufficient technological pay-off. Consequently, DARPA is very tolerant of failure if the potential payoffs are high enough.

- *Access to defense procurement:* DARPA maintains many formal and informal structures to ensure that its projects align with the needs of the armed forces and that its technologies are absorbed and utilized by the military.[82] By doing so, DARPA research projects leverage the Department of Defense's vast procurement budget to spur development. Such spending creates markets for nascent technologies or experimental research applications, which, in some cases, leads to broader commercialization.

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78. Bonvillian, *The Connected Science Model for Innovation*; Congressional Research Service, *Defense Advanced Research Projects Agency*.
79. Bonvillian, *The Connected Science Model for Innovation*.
80. Ibid.
81. Congressional Research Service, *Defense Advanced Research Projects Agency.*
82. Defense Advanced Research Projects Agency, *Innovation at DARPA* (Arlington: Defense Advanced Research Projects Agency, July 2016), 16, https://www.darpa.mil/attachments/DARPA_Innovation_2016.pdf.

Other federal agencies—and even private companies—have copied aspects of the DARPA model, seeking to emulate its success. In 2006, the Office of the Director of National Intelligence launched the Intelligence Advanced Research Projects Activity (IARPA), and in 2009, the Department of Energy started the Advanced Research Projects Agency–Energy (ARPA-E), which received positive reviews from a recent National Academy of Science's study.[83] In 2012, the former director and deputy director of DARPA started the Motorola Advanced Technology and Projects group, which is now a division of Google.[84]

Sematech: Responding to the Japan Challenge

In the 1980s, the U.S. semiconductor industry faced intense competition from Japanese companies producing higher quality chips, in part due to Japanese government support.[85] The U.S. share of global semiconductor production fell from around 60 percent in 1972 to around 40 percent in the late 1980s.[86] A 1987 Defense Science Board task force warned that the rise of foreign competitors not only threatened U.S. semiconductor manufacturing capacity, but also risked ceding technological leadership.[87] In response, Washington and U.S. semiconductor producers launched several initiatives to revive the industry.

The most notable effort was the Sematech (short for "semiconductor manufacturing technology") R&D consortium to revive the U.S. semiconductor industry. Founded in 1987, Sematech convened 14 U.S. corporate members together with leading universities and national laboratories in order to rationalize supply chains, share know-how, and collaborate to reduce product costs and defects.[88]

To comply with anti-trust law, Sematech was explicitly barred from manufacturing chips for sale and focused instead on generic technology.[89] Sematech was designed as a temporary, five-year project with a budget of $1 billion. The Defense Department supervised the project through DARPA and provided half of the budget, with the rest coming from industry. Government funding for Sematech was extended for three extra years, eventually totaling nearly $850 million. In 1996, federal funding was ended at the industry's request, and the consortium was eventually restructured as an international semiconductor research organization among U.S. and foreign producers; starting in the early 2000s, this has included Japanese companies.

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83. National Academies of Sciences, Engineering, and Medicine, *An Assessment of ARPA-E (Washington, DC: National Academies Press, 2017).*

84. Regina E. Dugan and Kaigham J. Gabriel, "'Special Forces' Innovation: How DARPA Attacks Problems," *Harvard Business Review* 91, no. 10 (2013): 74–84, https://hbr.org/2013/10/special-forces-innovation-how-darpa-attacks-problems.

85. As discussed earlier, Japan's VSLI program coordinated Japanese semiconductor manufacturers and designers. By 1988, Japanese chip makers achieved more global market share than U.S. competitors.

86. Michaela D. Platzer and John F. Sargent Jr., *U.S. Semiconductor Manufacturing: Industry Trends, Global Competition, Federal Policy* (Washington, DC: Congressional Research Service, June 27, 2016), http://cdn2.hubspot.net/hubfs/409470/documents/CRS_report.pdf.

87. Defense Science Board Task Force on Semiconductor Dependency, *Report of Defense Science Board Task Force on Semiconductor Dependency* (Washington DC: Department of Defense, February 1987).

88. National Research Council. *Government-Industry Partnerships for the Development of New Technologies* (Washington, D.C.: National Academies Press, 2003), 62.

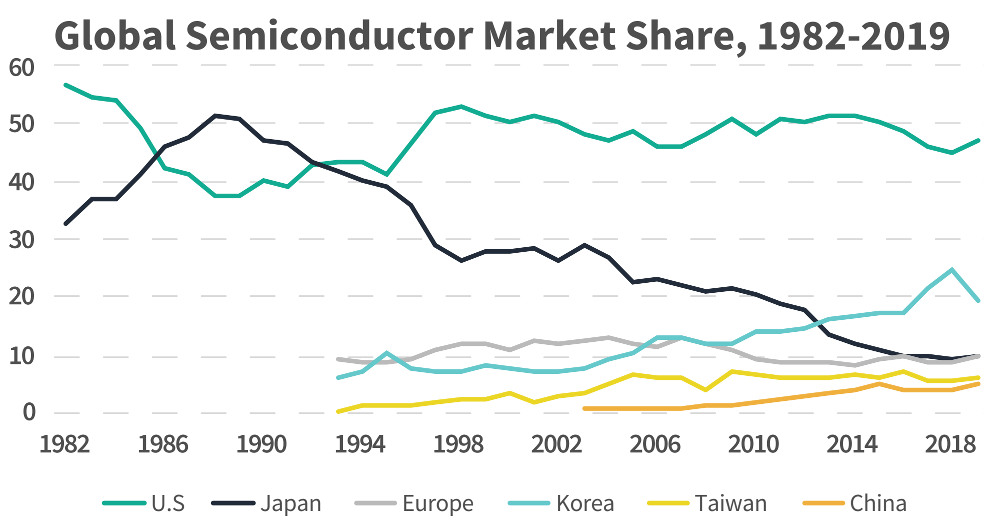
89. SEMATECH avoided anti-trust concerns by registering through the National Cooperative Research Act of 1984, which granted partial antitrust exemption to registered U.S. R&D consortia.

Despite initial friction within Sematech between chip designers and equipment manufacturers, under the project, U.S. semiconductor manufacturers improved productivity and achieved technical goals. For example, Sematech set a goal of reducing generational advantages in chip miniaturization from three years to two, which the industry has achieved since the mid-1990s. Aided by the emergence of a Korean semiconductor industry, by 1992, U.S. equipment suppliers achieved market share parity with Japanese competitors.

The U.S.-Japan Semiconductor Agreement

A key component of U.S. semiconductor industry's recovery was the 1986 U.S.-Japan semiconductor agreement. The agreement called for an end to Japanese dumping in the United States and third country markets and a (partial) opening of the Japanese market to foreign producers.[90] When the terms of the agreement were not implemented, President Reagan authorized economic sanctions against Japan, the first since the 1940s. Tokyo subsequently complied, and U.S. industry began to recover. The inventiveness and resilience of the industry aided by the breathing space of higher product prices then enabled a steady recovery, including a shift to new products, such as the microprocessor. The agreement—along with U.S. policy stance—arguably also sent a signal to the capital markets and to foreign competitors that the United States had no intention of exiting the industry.

By 1994, U.S. companies had captured 48 percent of the global semiconductor device market, while Japanese firms' market share fell to 36 percent.[91] This "double X" reversal in market share was unheard of in U.S.-Asian trade competition; other U.S. industries, such as televisions, had gone into irreversible decline in market share, profits, and viability. Reflecting the perception of Sematech's success, U.S. policymakers have since adopted it as model for public-private consortia, including for the National Alliance for Advanced Transportation Battery Cell Manufacture and the Department of Energy's SunShot Initiative to reduce solar energy costs.



Source: Semiconductor Industry Association, 2019 Factbook (SIA, 2019), https://www.semiconductors.org/the-2019-sia-factbook-your-top-source-for-semiconductor-industry-data/; Chart reproduced with permission.

90. United States General Accounting Office, *Observations on the U.S.-Japan Semiconductor Arrangement (Washington, D.C.: United States General Accounting Office, April 1987),* https://www.gao.gov/assets/80/76429.pdf.

91. Thomas Howell (Presentation on Sematech at CSIS, Washington DC, January 28, 2020).

Expert analysis—notably the 2003 Securing the Future report by the National Academy of Sciences (NAS)—attribute Sematech's success to several factors, including:

- *Private-sector commitment and leadership:* Industry leaders initiated Sematech out of fear that they were losing ground to foreign competitors. Prominent executives, especially National Semiconductor CEO Charles Sporck and Intel cofounder Robert Noyce, invested heavily in Sematech, and their leadership legitimized the consortium's research agenda. Under William Spencer's management, the consortium maintained strong links with industry, conducted rigorous internal evaluations, and required member companies to assign top-quality engineers to work with Sematech.[92]

- *Technology roadmaps:* Beginning in 1992, Sematech used its convening power to initiate road-mapping exercises that helped industry collectively identify and target common challenges. The NAS report found that roadmaps helped Sematech members leverage vast industry R&D more efficiently and more cooperatively.[93] For example, Sematech helped members to focus their efforts on supporting the struggling domestic manufacturing tool industry, particularly for lithography tools, and to improve total quality-control processes.

- *Clear use for research:* Sematech succeeded in transferring its technologies and ensuring that they were implemented, in large part because half of the consortium's operating force consisted of member-company assignees. Upon return to their companies, these assignees, who were well-respected within their firms and within industry, advocated for the adoption of Sematech-developed and validated technology.[94]

- *Relationship with vendors and academia:* Sematech helped chip designers improve their relationships with vendors through increased research contracts, joint road-mapping, and technical assistance. Federal involvement also helped strengthen previously limited industry connections to national labs. For example, Sematech worked with Sandia national laboratory to launch several cooperative research and development agreements for R&D, including in tool design and performance reliability.[95]

- *Development of industry standards:* Prior to Sematech, the lack of common standards for device-makers resulted in multiple—and expensive—inefficiencies. Sematech helped establish industry-wide enforceable standards, including the Computer Integrated

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92. National Research Council. *Government-Industry Partnerships for the Development of New Technologies* (Washington, DC: National Academies Press, 2003), 14, https://www.nap.edu/catalog/10584/government-industry-partnerships-for-the-development-of-new-technologies.
93. National Research Council, *Securing the Future: Regional and National Programs to Support the Semiconductor Industry* (Washington, DC: National Academies Press, 2003), 99, https://www.nap.edu/catalog/10677/securing-the-future-regional-and-national-programs-to-support-the.
94. For a discussion of the assignees, see: U.S. House of Representatives Committee on Science, Space, and Technology Subcommittee on Transportation, Aviation and Materials and Subcommittee on Science, Research and Technology, *Federal Research Policy and the American Semiconductor Industry, 101st Cong., 1st sess. (November 8, 1989), 36. For specific examples of Sematech-developed technologies cited by members as contributing to members' operations, see Government Accountability Office, Sematech's Efforts to Develop and Transfer Manufacturing Technology* (Washington, DC: Government Accountability Office, May 1991), 11.
95. Sandia National Laboratories, *Electronics Research at Sandia* (Albuquerque, NM: Sandia National Laboratories, August 6, 1997), https://www.sandia.gov/media/old_factsheets/facts19.htm.

Manufacturing framework, which defines specific services that enable application interoperability among components from multiple suppliers.[96]

- *Enhanced equipment industry competitiveness:* A key contribution of Sematech was the enhanced competitiveness of the U.S. equipment industry. This was facilitated by the rise of the South Korean semiconductor industry, which initially relied on U.S. equipment suppliers in order to compete. The rapidly growing Korean demand for U.S. equipment boosted the revenues and therefore the research of U.S. firms, thereby enhancing their competitiveness.

Sematech helped rally a stagnating industry, accelerate U.S. technological advances, and establish institutional best practices and standards with long-term significance.[97] It is difficult to quantify the direct impact of Sematech, but the 2003 NAS report concludes that the consortium reduced the R&D expenditures of its membership.[98] Like other industrial policies, some Sematech decisions did fail: for example, the consortium poured millions of dollars into equipment manufacturer GCA Corporation, only for the company to close when competitors developed superior technology.[99]

The strength of the U.S. policy response ultimately consisted of multiple collaborative and reinforcing actions. The industry organized itself into Semiconductor Industry Association (SIA) and advocated for federal support. Washington launched a series of trade negotiations with the Japanese and used enforcement tools when necessary. And Sematech brought together competitive companies with very diverse needs and views around a common objective.

Takeaways

DARPA and Sematech are two prominent examples of the many U.S. federal programs that support the broader innovation ecosystem and help develop new critical technologies. Several findings emerge from our study of these initiatives:

- **Government procurement can create markets for early-stage technologies.** Many U.S. innovation programs, including DARPA, rely on the government as a large consumer to spur development of early-stage technologies without commercial markets. Defense procurement programs, in particular, have a history of helping to encourage development and production of specialized technologies that are later adapted for commercialization.

- **Under the right circumstances, public-private R&D consortia improved competitiveness.** Congress and the semiconductor industry developed Sematech in the context of a perceived national emergency that created a "crisis of opportunity." The rapid-response mindset helped inculcate mission urgency, encouraged companies

96. Scott Hawker, "SEMATECH computer integrated manufacturing (CIM) framework architecture concepts, principles, and guidelines, version 0.7," *SEMATECH, Inc*, December 30, 1996, http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=6DDB65346D3DC9549281C8ADC411F502?doi=10.1.1.200.7445&rep=rep1&type=pdf
97. Hof, "Lessons from Sematech."
98. National Research Council, *Securing the Future*, 275.
99. Katie Hafner, "Does Industrial Policy Work? Lessons From Sematech," *New York Times*, November 9, 1993, https://www.nytimes.com/1993/11/07/business/does-industrial-policy-work-lessons-from-Sematech.html.

to send high-quality talent, and preserved necessary political and corporate support. However, such partnerships are not a panacea, and they should be adapted to fit the challenges at hand.

- **Successful federal programs relied on high-quality talent.** Both DARPA and Sematech have boasted extremely high-quality staff that maximized substantial resources to keep up with rapid technological changes. Future technology programs that do not have the resources to attract—and retain—top technical expertise are unlikely to achieve their mission. Sustained and substantial resources commensurate with the task are essential.

- **Flexible management and close cooperation with industry helped federal programs keep pace with rapid technological change.** DARPA maintained deep industry knowledge through quick turnover cycles and long-term partnerships with top research institutions. Sematech succeeded in large part because leading semiconductor experts dedicated their time to the effort, bringing crucial tacit knowledge with them.

- **Public-private cooperation connected diverse stakeholders in the innovation ecosystem.** Such programs facilitated transfer of knowledge by providing an institutional setting for collaboration among disparate, complex actors. Long-lasting linkages created during these partnerships yield social benefits long after individual programs expire. Critically, these connections also established a base of customers that would absorb and apply new technologies developed by federally funded research, rather than ignore them.

- **Tolerance for risk and failure improved outcomes of federal research subsidies.** DARPA support provided funding for risky, pre-competitive technologies that could not obtain sufficient private capital. Some failures were inevitable as a result of this ambitious vision to pursue technological breakthroughs.

- **Industry consortia were occasionally criticized for cabal-like practices.** While Sematech obtained legal anti-trust exemptions, it faced criticism for favoring large incumbent firms over smaller market participants.

Principles for a Revitalized U.S. Innovation Strategy

The effectiveness of federal policies often depends on how success is evaluated. From a purely theoretical view of economic efficiency, government intervention can sometimes lead to an inefficient allocation of resources. However, the economic history of the United Sates is replete with examples of government-industry cooperation to develop new technologies, often generating new industries and positive societal spillover effects in the process. The politicized narrative describing government bureaucrats as arbitrarily "picking winners" ignores the many clear successes of government-industry cooperation. As the cases detailed in this report have illustrated, federal action can focus and catalyze efforts to develop critical technologies vital to national security and sustainable economic progress, without unduly distorting the marketplace.

All of the world's leading economies, including the United States, embrace multiple policies that channel resources towards targeted sectors. Policymakers are now considering new paradigms for public- and private-sector cooperation to address challenges in today's global economy, in particular the behavior of competitors that target key technologies and provide massive support through a variety of mechanisms ranging from trade policy to subsidies to theft.[100]

Drawing on observations and lessons from previous European, Japanese, and U.S. experiences, we offer a number of core principles for a revitalized U.S. innovation strategy:

1. DEFINE A CLEAR MISSION

Innovation strategy should begin with clear overarching goals. Doing so will signal long-term federal support and help marshal private investment while keeping all stakeholders focused and working in the same direction (as with Sematech). At the program level, a well-defined goal empowers officials to course-correct if initial approaches stall, to ensure accountability, and to engender a sense of urgency for a process that could otherwise lead to wasteful spending. Officials should maintain flexibility in how they achieve their goals to accommodate changes in market dynamics and research breakthroughs.

100. U.S. Senate Committee on Small Business & Entrepreneurship, *Made in China 2025 and the Future of American Industry*.

2. INVEST IN THE FOUNDATIONS OF INNOVATIVE CAPACITY

Targeted federal interventions should be supported by ample investments in the broad underpinnings of innovative capacity, such as physical infrastructure; basic research and development; primary and secondary education that produces high-quality, inclusive outcomes; and high-skilled immigration. Policies targeted at specific technologies should not crowd out political space for these necessary horizontal investments.

3. SUPPORT CRITICAL TECHNOLOGY CATEGORIES

Policymakers can use targeted federal support both to address market failures and to help bring new technologies to market. Government intervention should support critical sectors and broad technology categories (such as AI), not pick specific companies or narrow applications (such as a certain machine learning algorithm). Federal policy can help correct market failures by:

- Compensating for underinvestment in non-captive public research that yields positive externalities;
- Correcting for insufficient financing when long timeframes are needed to realize R&D benefits for certain key strategic products;
- Accelerating development of technology categories with large first-mover advantages;[101]
- Leveling out the negative impact of trade-distorting measures by foreign competitors; and
- Overcoming scaling challenges, including the "valley of death" between academic research and commercial application.

Government intervention is also suitable to support R&D for technologies that are primarily of interest for national security rather than commercial reasons.

4. TAKE RISKS AND TOLERATE FAILURES

Federal funding can help where private actors, driven by purely market forces, may not have sufficient tolerance to realize the long-term benefits of riskier investments. In cases involving high-risk technologies, it is unlikely that government funding will crowd out private capital; on the contrary, it often serves to de-risk technologies to the point that the private sector can see a path forward for a return on investment.

Failures are an inevitable byproduct of risk and must be recognized as part of the scientific process. Programs and projects can fail through a changing competitive environment, management issues, or inadequate funding. When failures do occur, policymakers should transparently acknowledge and learn from them in order to refine the underlying policy and possibly discontinue the project. A long-term view is required, as success in frontier technologies is often incremental over several years, and efforts which initially appear to be failures can eventually pay substantial dividends. Still, program managers must have the ability and political space to drop projects and recommit resources as appropriate.

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101. David H. McCormick, Charles E. Luftig, and James M. Cunningham, "Economic Might, National Security, and the Future of American Statecraft," *Texas National Security Review 3, no. 3 (Summer 2020), https://tnsr.org/2020/05/economic-might-national-security-future-american-statecraft.*

5. KEEP PROGRAMS FLEXIBLE

Direct government intervention will be most effective and cost-efficient if it has a clear mission with measurable intermediate deliverables and regular assessments. At the same time, program design should allow for flexibility. Policymakers should welcome an outcome in which an R&D program aiming at technology A ends up supporting technology B instead, if the actual and practical results point in that direction. For example, in today's context, efforts to support near-term 5G telecommunications technologies may end up contributing to leadership on 6G instead—and that may eventually constitute a success towards the goal of regaining sectoral leadership.

6. USE PUBLIC-PRIVATE PARTNERSHIPS TO DEVELOP TECHNOLOGY ROADMAPS, PRODUCTION CAPABILITIES, AND MARKETS FOR FEDERALLY FUNDED RESEARCH

Public-private partnerships combine the private sector's superior market information with government's strategic perspective in order to establish shared priorities or targets. Independent technical experts should vet these targets to determine viability and mitigate bias. Successful partnerships encourage industry to take ownership, often through co-financing, and to contribute senior high-quality representatives who can share technical know-how. Public-private partnerships have also proven successful in coordinating applied research efforts and in supporting production capabilities.

It is also important to foster a customer base for the uptake of the technologies developed by government research organizations and consortia. This ensures that federally funded research is used and absorbed by target sectors, rather than ignored, and it creates a positive feedback loop to focus government research on productive areas. The research organizations that have succeeded have done so in part by utilizing formal and informal structures to develop collaboration with their customers.

7. GENERATE DEMAND FOR EARLY-STAGE TECHNOLOGIES USING GOVERNMENT PROCUREMENT POWER

In addition to R&D spending and supply-side incentives, government can use its procurement power to stimulate demand and create markets for early-stage technologies. By acting as a consumer, government can accelerate development of technologies using market incentives. Such policies should be used judiciously to support priority sectors or technology categories, not individual companies, while maintaining competition among firms. Procurement programs should build in tripwires and benchmarks for reducing reliance on government support over time while transitioning to commercially viable models.

8. SET STANDARDS AND ACCELERATE REGULATORY CYCLES TO REDUCE UNCERTAINTY

Private standard-setting groups, often working with federal regulatory agencies, can help catalyze innovation by codifying and harmonizing technical standards across complex supply chains. Similarly, regulators can support the deployment and commercialization of early-stage technologies by expediting initial regulatory approvals and setting clear national guidance to reduce uncertainty.

9. MAXIMIZE FUNDING TRANSPARENCY TO MINIMIZE RISK OF POLITICAL CAPTURE AND RENT SEEKING

Industrial policies are criticized for enabling rent-seeking behavior and political capture, which occurs when a firm receives support for political reasons rather than competitive capacity. Encouraging public scrutiny of partnerships and establishing accountability mechanisms are important safeguards to minimize the risk of misuse of taxpayer funds. Major programs should have a designated inspector general role to monitor for misallocation of funds and ethics violations.

10. ADHERE TO AND ENFORCE INTERNATIONAL RULES

Any industrial strategy should adhere to agreed-upon international rules, such as the World Trade Organization Agreement on Subsidies and Countervailing Measures or the Government Procurement Agreement. Policies that violate the letter or the spirit of such conventions will undermine efforts to discipline unfair trading practices and will isolate allies and partners. Innovation strategy should not serve as a pretext for restricting international trade or investment, but the United States should take appropriate trade actions to discipline countries that violate their commitments.

A Way Forward

The United States faces many daunting economic challenges, from a more assertive China to the severe disruption caused by Covid-19. The last two decades have proven that laissez-faire approaches with inadequate federal investments are insufficient to tackle these issues, and that more commitment of public resources is required. The massive government expenditure to mitigate the impact of Covid-19 underscores the need for robust federal research, incentives for private research *and development*, and measures to reduce risk for providers of new technological solutions.

Helpfully, there are many instructive examples, especially in the United States, of successful government programs to stimulate technological development in the framework of a market-oriented democracy. Policymakers, learning from experience, can reconceptualize innovation strategy to meet contemporary challenges in a globalized economic landscape. Government-led investment is part of the solution, but it is not a panacea, and it should play a constructive role alongside private-sector activities and other federal actions.

As policymakers consider the principles outlined in this report and debate new forms of innovation strategy, there are five broad areas on which initial efforts could usefully be focused:[102]

- **Improve STEM education outcomes and inclusivity.** While targeted policies can yield short-term breakthroughs, long-term investment in the U.S. innovation base will ensure the country remains at the technological frontier in science. A successful approach requires improving educational outcomes, starting with making STEM (science, technology, engineering, and mathematics) education more inclusive.

- **Increase federally funded R&D and programs that transition R&D to the market.** Policymakers should reverse decades of underinvestment in both national infrastructure and federally funded R&D. While doing so, they should expand mechanisms and incentives that help move technologies developed with federally funded R&D to market, such as the national laboratories' industry contracting programs.

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102. Innovation strategy and related recommendations will be addressed in more detail in the forthcoming CSIS Trade Commission.

- **Attract foreign talent.** Policymakers should reaffirm the United States as the premier destination for foreign talent by expanding employment-based, high-skilled immigration visas and providing a path to citizenship for foreign-born STEM doctorate recipients.

- **Leverage government purchasing power to create markets for early-stage technologies.** Local, state, and federal authorities can use their budgets to accelerate the commercialization and domestic production of early- to mid-stage technologies, such as upgrading to electric vehicles and adopting artificial intelligence applications to manage large government datasets.

- **Provide institutional support to enhance policymakers' technical knowledge.** The increasing pace and complexity of technological change means that policymakers require a ready source of technical literacy to write legislation dealing with issues of science and technology. To address this need, Congress should consider reauthorizing the Office of Technology Assessment (OTA) to provide robust and actionable briefings on emerging technologies for members and their staff.[103] A revived OTA would assess global market share in emerging technologies and how that could impact U.S. competitiveness and national security. Such assessments would inform and orient innovation strategy.

For decades, many U.S. politicians and economists have viewed industrial policy with skepticism. Failures of some government-supported projects were exploited to deepen perceptions that the state inefficiently "picked winners" and to establish a narrative of U.S. policy that ignored the many successes. The success and growth of foreign industrial policies have forced policymakers to reevaluate prior attitudes and biases about the optimal role of the public and private sectors. The choice facing officials today is not a simple binary one between free-market fundamentalism and centrally planned economic activity. Instead, policymakers can learn from the vast experience of the United States and its allies to design innovation strategy that helps meet and win the challenges of the twenty-first century.

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103. A February 2020 Information Technology and Innovation Foundation (ITIF) White Paper outlines several helpful suggestions for reviving OTA. Robert D. Atkinson, "A Fresh Start for the OTA," *Information Technology & Innovation Foundation*, February 21, 2020, http://www2.itif.org/2020-fresh-start-ota.pdf.

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