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Semiconductors and the Calculation of the Balance of Power

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Abstract

How will assessments of the future balance of power be affected by the profound importance of semiconductors for modern militaries and for global and local economies? I argue that four overarching characteristics of the semiconductor industry, each exacerbated by the specifics of U.S.-China relations, render the anticipation of shifts in the balance of power remarkably difficult. The industry is highly dynamic and unavoidably sensitive to subtle and unpredictable developments; innovation is driven by a commercial sector increasingly divorced from military needs; the quantities and types of chips needed by militaries and their ability to reliably secure them is increasingly unpredictable; and producing and accessing chips in major conflict environments would be exceptionally challenging. The profound importance of semiconductors in great power politics greatly reduces the ability to anticipate shifts in the balance of power with any certainty.

I. Introduction

Cutting edge semiconductor chips power modern military capabilities, increasingly wide swaths of conventional military forces, and even everyday civilian life, yet the literature on their impact on great power politics and interstate relations remains remarkably sparse and incomplete. While there has been an influx of largely limited and issue-specific government, think tank, and news coverage of semiconductors, Chris Miller's *Chip War* seems the only comprehensive account of the geopolitical history of microchips. Furthermore, the author of this thesis has found no attempts to situate semiconductors within international relations theory or to explain its structural impact on interstate relations.[1] This paper aims to begin to fill that gap and

[1] Chris Miller, *Chip War: The Fight for The World's Most Critical Technology* (Scribner, 2022).

explore the significant impact of semiconductor pervasiveness and indispensability on assessing the distribution of power, both as it relates to the system regardless of variations in polarity, and as specifically applied to today's multipolar world in which no great power is close to achieving semiconductor self-sufficiency.

Semiconductors are indispensable for modern weapons systems, telecommunications infrastructure, modern vehicles, advanced electronics including cell phones and computers, artificial intelligence, and nearly all modern technology.[2] These systems and the industry which drives them are highly complex: a single Apple A15 Bionic iPhone chip contains 15.8 billion transistors powering multiple complex chips each designed and manufactured in highly globalized and fragile supply chains.[3] Neither China nor the United States is capable of producing such advanced chips solely within its borders, and the notoriously intricate industry relies on a network that spans the world, with each new generation of chips requiring larger investments and additional complexity.[4] High-end processors—just one of many types of chips—are typically designed in America; manufactured in Taiwan using equipment from the Netherlands and from across the world, software from America, and silicon wafers and chemicals from Japan; assembled and tested in Southeast Asia; and packaged in Taiwan and China, the latter of which supplies most of the critical silicon- and gallium-based raw materials.[5]

The United States, which has been losing manufacturing share since the 1990s, relies heavily on chips manufactured in massive, $10-20B+ globally-integrated facilities concentrated in Taiwan that require 1,000 times fewer airborne particles than a sterile hospital operating

[2] President's Council of Advisors on Science and Technology, "Report to the President: Revitalizing the U.S. Semiconductor Ecosystem," 8.
[3] Samuel K Moore and David Schneider, "The State of the Transistor in 3 Charts," IEEE Spectrum, March 29, 2023.
[4] Alex Capri, "Semiconductors at the Heart of the US-China Tech War," Hinrich Foundation, January 17, 2020, 17.
[5] Ibid, 19.

room.[6] The principal competitor of the U.S., China, remains several generations behind global chip leaders on several key technologies despite decades of state initiatives and the largest semiconductor end market, and Chinese capabilities are being set farther behind by recent export bans from the U.S. and its allies.[7] The scale of demand is unrivaled; China required more net imports of semiconductors than imports of crude oil every year from 2017-2021 except one, reaching $424B of semiconductor imports and $270B of net imports (imports minus exports) in 2021.[8] The world's two most powerful states cannot reliably and securely source the indispensable semiconductors that power their militaries and their economies, and the challenges they face are likely to mount.

In section II, I identify four key overarching characteristics of the semiconductor industry, and note the effects of these fundamental attributes of the industry are exacerbated by the current U.S.-China distribution of power. First, I explore the ongoing rapid evolution, dynamism, inherent complexity, precarious supply chains, and entrenched geographic dispersion of the industry. Second, I detail the complications of innovation being unavoidably driven by the commercial sector, and suggest commercial and military needs will increasingly further diverge. Third, I demonstrate that the quantities and types of chips needed by militaries, as well the ability to reliably source such chips, are increasingly unpredictable. Fourth, I argue that the first three characteristics and the related formidable challenge of onshoring and attempting to secure semiconductor supplies render the conversion of wealth, population, and conventional industrial

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[6] Ian King, Adrian Leung, and Demetrios Pogkas, "Chip Shortage 2021: Semiconductors Are Hard to Make and That's Part of the Problem," Bloomberg, May 6, 2021.
[7] Alex He, "China's Techno-Industrial Development: A Case Study of the Semiconductor Industry," Centre for International Governance Innovation, 2021, 9.
[8] Chinese Semiconductor Industry Association, "2021年中国集成电路产业运行情况 ('The Operation of China's Integrated Circuit Industry in 2021'). CSIA, March 14, 2022, https://web.csia.net.cn/newsinfo/2523503.html; Global Times, "China May Spend $100 Billion More on Crude Oil Imports in 2022 amid Surging Global Oil Prices: Experts," April 13, 2022.

bases into military power during a conflict highly unreliable. Together, I argue these dynamics of the semiconductor industry highly complicate the ability to anticipate shifts in the balance of power, and that this uncertainty is largely structural and challenging if not impossible to ameliorate.

In section III, I briefly outline the importance of semiconductors for both conventional and next-generation military use.

In section IV, I demonstrate the complexity of the semiconductor industry, assess its globalized and intricate supply chains, and outline the geographic concentration of several key steps in the production process.

In section V, I provide the evidence for my argument outlined in section II. For each of the four points, I analyze the mechanisms through which it reduces the ability to anticipate shifts in the balance of power, emphasize why specific U.S.-China dynamics exacerbate key issues, and describe why the consequent uncertainty is unlikely to be ameliorated. This section will employ a mix of financial analysis, case studies, and existing and novel data sets.

In section VI, I analyze two possible counterarguments and argue that neither mitigate the difficulty in anticipating shifts in the balance of power. First, I examine the claim that there is a high likelihood that China will be able to successfully imitate cutting-edge semiconductor production. Second, I entertain the claim that the Russo-Ukrainian War suggests semiconductors are not critical for modern conflict, and instead conclude that the evidence supports their essential nature.

In section VII, I conclude and analyze the potential consequences of the inability to anticipate shifts in the balance of power. While I note that this uncertainty raises the potential for dangerous miscalculations, I suggest that the likely enduring shared economic and even military semiconductor interdependence of the U.S. and China may prove a powerful force for peace.

II. Argument Overview

I identify four overarching characteristics of the semiconductor industry and their relevance to modern militaries and economies and conclude that these characteristics render anticipating shifts in the future balance of power remarkably difficult. For each dynamic, I identify the contributing aspects of the industry, first covering those applicable to the industry and militaries regardless of the current distribution of power, and then note how U.S.-China dynamics exacerbate the effect of these characteristics on the ability to assess the future balance of power. Throughout, I note how most of the factors contributing to these dynamics are largely unavoidable and are likely to become more severe over time.

The first characteristic is the dynamism and unpredictability of the industry. I identify and analyze five relevant aspects of semiconductor production: the industry is hyper-competitive with a demanding business cycle, threatening the survival of all firms; supply chains are extremely tight; the industry unavoidably relies on a few key firms; foundries take years to build; and current manufacturing leaders outside of the U.S. and China are critical to the national security of their countries.

The second characteristic is the dominance of the commercial market for innovation and production. I explore six key aspects of the industry: the commercial market for semiconductors dwarfs military spending; the commercial market can no longer viably produce old parts and military-specific chips critical for conventional weapons; the military is increasingly reliant on the commercial market for chips, mainly manufactured in Taiwan; military and civilian semiconductor needs are increasingly diverging; and the influence of the Chinese market and sophisticated industrial espionage routinely leads to technology transfers.

The third characteristic is the inability to identify and reliably secure the types and amounts of chips required by militaries. I identify and analyze nine key aspects driving this inability: the difficulty of predicting future capabilities of chips and their military applications; the current challenge of procuring both mature and cutting-edge chips; the disappearance of American manufacturing and the challenges of industrial policy; the growing tension between the goals of the U.S. and its allies; the uncertainty surrounding export controls; the Chinese response to export controls; the potent threat of dumping; the uncertainty of Chinese chipmaking initiatives; and the varying incentives to exaggerate or hide semiconductor capabilities.

The fourth characteristic is the likely breakdown of semiconductor production and innovation in even a mild conflict environment. I explore two key aspects of the industry: the severe effect of conflict on global supply chains and the uncertainty surrounding the extent and usefulness of Chinese stockpiles.

III. Importance of Chips for Modern Militaries

Semiconductors have been a critical focus and a competitive edge for the American military since their invention, despite the best efforts of the Soviet Union and Japan. In 2023, that edge is potentially declining with the rise of China, America's first military and economic peer-competitor. Much of the inspiration for this section comes from *Chip War*, which contains a thorough and engaging history of semiconductors and their strategic importance.[9]

[9] Chris Miller, *Chip War: The Fight for The World's Most Critical Technology* (Scribner, 2022).

Fairchild Semiconductor, the first commercially successful semiconductor company, was founded in what is now Silicon Valley days before the launch of Sputnik and soon benefited tremendously from American Cold War needs. The Apollo Program almost single-handedly transformed Fairchild from $500K sales in 1958 to $21M in 1960.[10] By 1965, chips had solidified their place in national defense; that year, defense dollars bought 72% of integrated circuitry (IC) produced (the rest were purchased for space programs), and 20% of all IC was sold to the Minuteman program.[11] Only later did semiconductors become relevant to the commercial market, and the first IC produced for commercial end markets, used in a Zenith hearing aid, was designed for NASA satellites.[12]

Semiconductors soon transformed the effectiveness of American missiles through their computing power, size, and low cost. Previously, the legacy Sparrow III anti-aircraft missile radar system relied on hand-soldered vacuum tubes; it registered a hit rate of 9.2% during the Vietnam War, compared to 66% which malfunctioned and the remaining ~24.8% which missed.[13] It was semiconductors that allowed for devastating guidance systems used in the Paveway and then Tomahawk missiles and later in F-117 Nighthawk stealth fighter and Patriot anti-ballistic missile systems.[14] These developments, after some failures in the 1980s, powered the overwhelming military success of the first Gulf War through surveillance, communication, and computing power, leading to articles such as the *New York Times*' "War Hero Status Possible for Computer Chip," declaring the war as a "triumph of silicon over steel."[15]

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[10] Noyce, Robert N. "Integrated Circuits in Military Equipment." *IEEE Spectrum* 1, no. 6 (1964): 71–72.
[11] "Minuteman Is Top Semiconductor User," *Aviation Week & Space Technology*, July 1965, 83; Institute for Defense Analyses, "The Role of the Department of Defense in the Development of Integrated Circuits," 1977, 83.
[12] T. R. Reid, *The Chip: How Two Americans Invented the Microchip and Launched a Revolution* (New York, NY: Random House, 2001), 151.
[13] Naval Air Systems Command, "Report of the Air-to-Air Missile System Capability Review," 1968, 140.
[14] Kenneth P. Werrell, *The Evolution of the Cruise Missile* (Maxwell Air Force Base, AL: Air University Press, 1997), 136.
[15] William J. Broad, "War Hero Status Possible for the Computer Chip," *The New York Times*, January 21, 1991.

Semiconductors were essential to the American Cold War effort and the "offset strategy" against Soviet conventional superiority in Europe. Bill Perry, who led the strategy which enabled better guidance, communication, command and control, worked closely with his longtime singing partner and close friend/ally Robert Noyce, a co-founder of both Fairchild and Intel and the "Father of Silicon Valley."[16] By the end of the Cold War, the Soviets still relied on guidance computers (using old American technology) to put a missile back on a pre-programmed route if it differed; in the 1980s, American missiles were calculating their own path to the target in real-time, and Fairchild's Illiac IV chip powered and connected sensors to track Soviet submarines.[17] American semiconductors drove critical leaps in weapons systems, communications, navigation, and surveillance.

In the 21st century, semiconductors critical for artificial intelligence and supercomputers have heightened competition over access to chips with military uses. As of 2023, 95% of the market for AI accelerators needed to train AI models are designed by U.S. firm Nvidia and manufactured by TSMC;[18] Open AI and Microsoft reportedly spent hundreds of millions of dollars to train ChatGPT using supercomputers built with tens of thousands of Nvidia chips, [19] and deploying it to Bing users has been projected to cost billions more.[20]

Access to AI chips has therefore become important in U.S.-China relations and a motivation behind the recent semiconductor export bans.[21] China ostensibly leads in AI,[22] utilizing its

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[16] Miller, 98-99.
[17] Ibid, 147-148.
[18] Debby Wu, Ian King, and Vlad Sarov, "US Deals Heavy Blow to China Tech Ambitions With Nvidia Chip Ban," *Bloomberg*, September 2, 2022.
[19] Dina Bass, "Microsoft Strung Together Tens of Thousands of Chips in a Pricey Supercomputer for OpenAI," *Bloomberg*, March 13, 2023.
[20] Kif Leswing, "Meet the $10,000 Nvidia Chip Powering the Race for A.I.," *CNBC*, February 23, 2023.
[21] Gregory C. Allen, "Choking off China's Access to the Future of AI Image," Center for Strategic & International Studies, October 11, 2022.
[22] Daitian Li, Tony W. Tong, and Yangao Xiao, "Is China Emerging as the Global Leader in AI?," *Harvard Business Review*, February 18, 2021.

skilled workforce and data collection abilities to produce the most top AI-related papers in the world.[23] However, Chinese AI, including PLA projects, runs on American-designed chips manufactured in Taiwan. A PRC-run think-tank white paper estimates that in 2020, 95% of mainland Chinese domestic servers running AI workloads ran on Nvidia chips.[24] One study found nearly all AI chips in public 2020 Chinese People's Liberation Army (PLA) purchase records were designed by U.S. firms, despite restrictions on sale to the military and its suppliers.[25] The effectiveness of the export bans, the ability of China to eventually develop and manufacture its own AI chips, and the ability of the U.S. to capitalize on its AI chip advantage have critical implications for geopolitics.[26]

IV. Complexity of the Semiconductor Market

The following provides a very brief overview of the size and complexity of the semiconductor industry, which generated ~$574B of sales to end users in 2022 alone.[27] For a more complete description of the industry and its nuances, see **Appendix 1.** For an analysis of China's semiconductor weaknesses and relative semiconductor strengths, see **Appendix 2**. The U.S. imported ~$95B of semiconductors and was a net exporter of ~$25B;[28] China in 2021

[23] Ibid.
[24] China Academy of Information and Communications Technology (CAICT), "White Paper on China's Computing Power Development Index," September 18, 2021, English translation: https://cset.georgetown.edu/wp-content/uploads/t0402_compute_white_paper_EN-2.pdf
[25] Ryan Fedasiuk, Karson Elmgren, and Ellen Lu, "Silicon Twist: Managing the Chinese Military's Access to AI Chips," *Center for Security and Emerging Technology*, June 2022.
[26] Gabriel Dominguez, "The next Arms Race: China Leverages AI for Edge in Future Wars," *The Japan Times*, April 20, 2023.
[27] Semiconductor Industry Association (SIA), "Global Semiconductor Sales Increase 3.3% in 2022 Despite Second-Half Slowdown," February 3, 2023.
[28] Fernando Leibovici and Jason Dunn, "U.S. Trade of Semiconductors: Cross-Country Patterns and Historical Dynamics," *Economic Research: Federal Reserve Bank of St. Louis* 2022, no. 31 (December 7, 2022).

imported $424B of semiconductors and was a net importer of $270B.[29] Comparatively, China "only" imported ~$257B of crude oil in 2021 with an average import price of $68.5 per barrel.[30]

Figure 1 displays the total consumption of semiconductors in 2021 by region. Source data can be found in the following footnote.[31]

Semiconductor End Market, 2021

(USD, $B)	Total Market	U.S. Presence	U.S. Share
China	$193	$96	49.9%
Asia Pacific & Other	151	73	48.6%
Americas	122	47	38.7%
Europe	48	24	50%
Japan	44	17	40%
Total Market	**$556**	**$258**	**46%**

Semiconductor Industry Association 2022 Factbook; World Semiconductor Trade Statistics (WSTS)

Note: U.S. Market Share Driven by High Value-Add from U.S. Design Companies

Figure 2 shows Chinese import, export, and net import data for semiconductors from 2017-2021. The data from the Chinese Semiconductor Industry Association is likely reliable, especially as it is consistent with other sources and import/export data is relatively observable. Source data can be found in the following footnote.[32]

Chinese Semiconductor Imports/Exports

(USD, $B)	2017	2018	2019	2020	2021
Imports	$260	$312	$306	$350	$424
Exports	67	85	102	117	154
Net Imports	**194**	**227**	**204**	**233**	**270**
Crude Oil Imports	162	240	242	179	257

**Data from Chinese Semiconductor Industry Association; Oil Imports from Global Times*

https://web.csia.net.cn/newsinfo/2523503.html

https://www.globaltimes.cn/page/202204/1259198.shtml

[29] Che Pan, "US-China Tech War: Chinese Semiconductor Output Surged 33 per Cent Last Year, Double the Growth Rate in 2020," *South China Morning Post*, January 17, 2022.
[30] "China May Spend $100 Billion More on Crude Oil Imports in 2022 amid Surging Global Oil Prices: Experts."
[31] Semiconductor Industry Association (SIA), "SIA 2022 Factbook," April 2022.
[32] "2021年中国集成电路产业运行情况 ('The Operation of China's Integrated Circuit Industry in 2021'); "China May Spend $100 Billion More on Crude Oil Imports in 2022 amid Surging Global Oil Prices: Experts."

There are five overarching categories of chips: logic; memory; analog; optoelectronic, discrete, and sensor components; and microprocessors (MPU), microcontrollers (MCUs), and digital signal processors (DSPs). Most modern electronics are powered by many of these chips together performing various functions. Logic chips are largely designed by American firms including Intel, Nvidia, AMD, and Qualcomm, as well as systems companies such as Apple, Google, Amazon, and Telsa who desire highly-customized chips.[33] Memory chips are largely designed and manufactured by the Korean Samsung and SK Hynix and the American Micron, although Micron operates much of its manufacturing in Southeast Asia. The remaining types of chips are largely designed and often produced in the U.S. and Europe, with the latter relatively strong in the automotive sector.[34]

Figure 3 displays the five overarching types of chips by 2021 sales volume**.** Source data can be found in the following footnote.[35]

Semiconductor Sales by Type, 2021

(USD, $B)	**Amount**	**% of Total**
Logic	154.8	28%
Memory	153.8	28%
Opto, Discretes, and Sensors	92.8	17%
MPU, MCU, and DSP	80.2	14%
Analog	74.1	13%
Total	**555.7**	**100%**

Semiconductor Industry Association 2022 Factbook; (WSTS)

These chips are either produced by "pure-play" foundries, typically in Taiwan, or by IDMs, which vary in location based on chip type. Memory fabrication capacity is mostly in

[33] Sam Shead, "Tech Giants Are Rushing to Develop Their Own Chips — Here's Why," CNBC, September 7, 2021.
[34] Bank of America Merrill Lynch Equity Research, "Moore and beyond: Primer on Technology and Market for Global Semiconductors," Bank of America Merrill Lynch, May 8, 2016.
[35] SIA 2022 Factbook.

Korea and Southeast Asia, although some are owned by the American firm Micron. Taiwan holds 63% of all foundry capacity for logic chips and manufactures 90% of all cutting-edge logic chips (under 10nm), with only Samsung currently competitive at the most advanced nodes.[36] The automotive sector tends to use larger chips, which allows them to be commonly built in Europe in Japan.[37] Cutting-edge foundries continue to grow in complexity and cost: a new 14-16nm fab is estimated to cost $13B; a 10nm, $15B; a 7nm, $18B; a 5nm, $20B; and over ten years a current state-of-the-art fab is estimated to cost $40B across initial capital expenditures and annual operating costs without upgrading it to new production nodes.[38] TSMC's new 2nm fab near Longtan Science Park in Taiwan is rumored to cost $32B, and the first iterations of 2nm and 1nm from this fab are expected to enter the market in 2026.[39]

Figure 4 shows global manufacturing capacity by location. Note that mainland China's ~15% market share includes foundries operated by Taiwan's TSMC and Korea's Samsung and HK Hynix in China. Some of this capacity is now unusable without foreign equipment. Source data can be found in the following footnote.[40]

Manufacturing Capacity by Node by Fab Location, Beginning of 2021

	United States	China	South Korea	EMEA	Japan	Taiwan	Other
≥ 0.18µ	16%	21%	7%	12%	17%	17%	11%
40nm - 0.18µ	12%	17%	10%	7%	14%	29%	12%
20nm - 40nm	17%	15%	27%	7%	0%	30%	4%
10nm - 20nm	12%	15%	29%	2%	24%	10%	9%
<10nm	**0%**	**0%**	**37%**	**0%**	**0%**	**63%**	**0%**

**Data from McKinsey; IC Insights, HIS Markit; SEMI World Fab Forecast Database*

36 Sullivan, Jake, and Brian Deese, Building Resilient Supply Chains, revitalizing American manufacturing, and fostering broad-based growth: The White House. 100-Day Reviews (2021), 35.
37 Ibid.
38 Stephen Ezell, "Moore's Law Under Attack: The Impact of China's Policies on Global Semiconductor Innovation," Moore's Law Under Attack: The Impact of China's Policies on Global Semiconductor Innovation, February 18, 2021, 15.
39 Xianmiao Yu, "沈榮津：台積1奈米廠落腳龍潭 ('Shen Rongjin: TSMC's 1nm Plant Settled in Longtan')," *經濟日報 ("Economic Daily News")*, November 22, 2022.
40 Semiconductor Industry Association, "2022 State of the Semiconductor Industry Report," November 2022."

The fabrication of chips relies on a large network of semiconductor manufacturing equipment (SME) suppliers primarily concentrated in the United States, Japan, and the Netherlands, as well as electronic design automation (EDA) tools. There are over 50 unique types of specialized SME alone needed for semiconductor production.[41] Back-end test equipment is used in the ATP process; test equipment is led by Japan and the United States, while packaging equipment market share is led by Japan, China, and the Netherlands (although the U.S. is at the forefront of technological innovation for advanced packaging).[42] Front-end SME, which is more technically advanced and represents a greater choke point for Chinese manufacturing, is led by America and Japan; this SME is used for lithography, etching, doping/ion implantation, deposition, and polishing or chemical mechanization planarization. The Dutch ASML is the only company capable of producing EUV lithography machines needed for creating circuit patterns on 5nm node or smaller chips.[43] EDA software is essential for designing and manufacturing chips, and three American firms (one owned by a German firm) lead the industry.[44] These firms also produce key intellectual property (IP) building-blocks bought by designers. The U.K.-based ARM provides a similar, essential licensing service for IP for microprocessors.[45]

After fabrication, these chips are sent for the assembly, test, and packaging (ATP) process. Many firms contract to outsourced A&T (OSAT) firms, while some IDMs operate their own facilities. While packaging was historically outsourced to East and Southeast Asia because

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[41] Antonio Varas et al., "Strengthening the Global Supply Chain in an Uncertain Era," Semiconductor Industry Association and Boston Consulting Group, April 2021, 20.
[42] FP Analytics, "Semiconductors and the U.S.-China Innovation Race," Foreign Policy, February 16, 2021.
[43] Cagan Koc and Debby Wu, "ASML Shrugs off China Chip Curbs amid Strong Demand Elsewhere," Bloomberg, November 11, 2022.
[44] Zeyi Yang, "Inside the Software That Will Become the Next Battle Front in US-China Chip War," MIT Technology Review (MIT Technology Review, August 18, 2022).
[45] The Economist, "Why Everyone Wants Arm," June 22, 2022.

of its labor intensity, the rise of a new procedure of carefully combing "chiplets" on a single circuit board has necessitated separate advanced packaging facilities.

Figure 5 shows total value added by region for each major category of semiconductor production. Note that DAO stands for "discrete, analog, and other" and A&T stands for "assembly and test." Source data can be found in the following footnote.[46]

Value Added by Activity and Region, 2021

	U.S.	China	South Korea	Europe	Japan	Taiwan	Other
Logic (Fabless)	67%	6%	4%	8%	4%	9%	3%
Memory (IDM)	28%	1%	58%	1%	8%	4%	1%
DAO (Hybrid)	37%	9%	6%	18%	21%	4%	6%
Design Total	**49%**	**5%**	**20%**	**8%**	**9%**	**6%**	**3%**
Equipment	**42%**	**1%**	**3%**	**21%**	**27%**	**1%**	**5%**
Materials	10%	19%	17%	6%	14%	23%	12%
Wafer Fabrication	**11%**	**21%**	**17%**	**9%**	**16%**	**19%**	**7%**
Packaging, A&T	**5%**	**38%**	**9%**	**4%**	**6%**	**19%**	**19%**
Overall	**35%**	**11%**	**16%**	**10%**	**13%**	**10%**	**5%**

**Data from Semiconductor Industry Assocation 2022, "State of the Semicodncutor Industry Report"*
https://www.semiconductors.org/wp-content/uploads/2022/11/SIA_State-of-Industry-Report_Nov-2022.pdf

Figure 6 shows production of key semiconductor materials. Note that China controls ~70% of polysilicon production capacity and nearly all of the world's gallium production and reserves but produces no meaningful quantities of wafers or advanced photoresists. Source data can be found in the following footnote.[47]

Key Semiconductor Inputs, Raw and Produced Materials, 2021

	U.S.	China	Korea	Europe	Japan	Taiwan	Russia	Ukraine	Other
Silicon	**3%**	**69%**	-	**3%**	-	-	**7%**	**1%**	**18%**
Critical Minerals*	**1%**	**52%**	-	**4%**	-	-	**4%**	**1%**	**38%**
Specialty Gases**	10%	17%	-	28%	2%	-	9%	30%	5%
Wafers	-	-	-	**15%**	**57%**	**17%**	-	-	**11%**
Photoresist	**15%**	-	-	-	**72%**	-	-	-	**13%**
Photomasks	**21%**	**12%**	**14%**	**12%**	**10%**	**16%**	**1%**	-	**13%**
CMP Slurries	41%	2%	-	-	45%	-	-	-	12%
Silicon Carbide	4%	38%	1%	30%	4%	-	-	-	23%
Wet Chemicals	12%	2%	-	46%	-	-	-	-	40%

** Includes gallium, germanium, indium, rare-earths, alumina, and palladium*
*** Includes neon, krypton, and xenon*
****Data from BCG; United States Geological Survey, White House 100 Day Supply Chain Report, CSET*
https://web-assets.bcg.com/52/6b/7217e856495a83ac0b8447a2187e/national-semiconductor-economic-roadmap-nser-dec2022.pdf

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[46] "2022 State of the Semiconductor Industry Report."
[47] Arizona Commerce Authority and Boston Consulting Group, "The National Semiconductor Economic Roadmap," December 2022.

Figure 7 shows the heavy reliance on the Chinese market of many American and other international chipmakers, sorted by firm value as of April 27, 2023 and highlighted by headquarters. The percent of revenue calculations are suitable indicators for integration with companies from each country, but not necessarily for the location of the end user. “B” and “S” means the companies record location based on the “bill-to” and “ship-to” or software usage location of their products. “HQ” refers to companies recording location based on the headquarter location of the customer. An empty cell indicates the company did not clearly label its method.

Enterprise	(USD, $MM)		CY2022		2021 Rev, CY (More Consistent Data)			
Value	**Name**	**Headquarters**	**Rev**	**EBIT**	**% U.S.**	**% China**	**Method**	**Type**
663,470	NVIDIA	United States	26,974	5,577	16%	26%	B	Fabless
393,670	**TSMC**	**Taiwan**	**76,428**	**37,880**	**64%**	**10%**	**HQ**	**Foundry**
283,653	Broadcom	United States	34,412	15,274	19%	-	S	Fabless
250,221	**Samsung Electronics**	**Korea**	**237,666**	**34,110**	**-**	**-**	**-**	**Memory**
242,420	ASML	Netherlands	22,372	6,869	9%	15%	S	Equipment
149,911	Texas Instruments	United States	20,028	10,095	10%	55%	S	Analog
135,927	Qualcomm	United States	42,958	14,541	4%	67%	S	Fabless
135,413	AMD	United States	23,601	1,264	28%	25%	B	Fabless
134,836	**Intel**	**United States**	**63,054**	**2,336**	**18%**	**27%**	**B**	**IDM**
96,265	Analog Devices	United States	12,579	4,256	33%	22%	S	Analog
95,296	Applied Materials	United States	26,253	7,820	9%	33%	S	Equipment
67,694	**Micron**	**United States**	**27,156**	**6,839**	**44%**	**18%**	**HQ**	**Memory**
66,457	Lam Research	United States	19,048	6,049	5%	35%	S	Equipment
59,489	**SK Hynix**	**Korea**	**35,089**	**5,355**	**40%**	**37%**	**S**	**Memory**
55,283	Cadence	United States	3,562	1,084	43%	13%	S	EDA
55,036	Synopsys	United States	5,173	1,112	46%	13%	S	EDA
52,487	KLA	United States	10,484	4,177	10%	29%	S	Equipment
50,832	Shin-Etsu	Japan	20,573	7,476	~17%	~8%	S	Wafers
50,792	NXP	Netherlands	13,205	3,778	9%	38%	S	Auto
50,242	Tokyo Electron	Japan	16,551	4,733	11%	28%	S	Equipment
48,839	Infineon	Germany	15,860	3,618	14%	29%	S	Auto
46,931	Microchip	United States	8,050	2,822	0%	-	-	Analog, MCU
38,967	**SMIC**	**China**	**7,273**	**1,500**	**22%**	**70%**	**HQ**	**Foundry**
36,770	STMicro	Switzerland	16,083	4,659	0%	-	S	Auto
36,457	Marvell	United States	5,920	398	11%	44%	S	Fabless
33,588	Mobileye	Israel	1,869	(37)	-	-	S	AV Auto
31,642	ON Semiconductor	United States	8,326	2,784	14%	~34%	B	Power, Auto
31,464	**GlobalFoundries**	**United States**	**8,108**	**1,261**	**60%**	**~6%**	**S**	**Foundry**
29,397	MediaTek	Taiwan	18,527	4,280	-	-	-	Fabless
27,063	Renesas	Japan	11,212	3,188	8%	23%	-	Auto
24,657	Naura	China	2,194	428	-	97%	-	Equipment
20,744	Monolithic Power Systems	United States	1,794	535	3%	58%	S	Analog, Power
18,654	ASE Technology	Taiwan	22,648	2,748	62%	- 11%	HQ	OSAT
17,790	Skyworks Solutions	United States	5,304	1,477	63%	19%	HQ	RF
17,108	ASM	Netherlands	2,547	657	26%	-	S	Equipment
16,671	Will Semiconductor	China	2,983	160	-	-	-	Analog, Power
16,060	Entegris	United States	3,282	570	23%	16%	S	Materials
15,926	Western Digital	United States	15,752	872	22%	47%	S	Memory
15,816	**UMC**	**Taiwan**	**9,409**	**3,505**	**11%**	**15%**	**-**	**Foundry**
14,447	AMEC	China	708	131	-	86%	-	Equipment
12,722	Lasertec	Japan	805	280	43%	- 10%	S	Photomasks
11,791	Lattice	United States	660	190	12%	55%	S	Fabless
11,146	Disco Corporation	Japan	2,081	802	- 7%	37%	-	Equipment
10,607	Wingtech	China	8,377	528	0%	-	-	IDM
10,098	Qorvo	United States	4,103	749	42%	32%	HQ	RF
9,633	**GigaDevice**	**China**	**1,336**	**409**	**-**	**-**	**-**	**Memory**
7,926	Wolfspeed	United States	874	(148)	19%	28%	S	Wide-Bandgap
6,984	JCET	China	5,023	455	50%	32%	S	Equipment
6,414	**Huahong**	**China**	**2,475**	**565**	**10%**	**74%**	**-**	**Foundry**
6,139	SG Micro	China	476	122	-	97%	-	Analog
5,251	GlobalWafers	Taiwan	2,373	845	- 13%	- 20%	S	Wafers
4,414	SUMCO	Japan	3,295	819	7%	13%	S	Wafers

Note: Broadcom, Samsung Electronics, Entegris, and Shin-Etsu all contain significant non-semiconductor business segments which are included in these numbers. Companies reporting in foreign currencies are translated into dollars at the historical exchange rate. The “fabless” and “IDM” labels are only applied to standard logic companies, while those which specialize in memory or analog chips are labeled accordingly, even though they are largely also IDMs. “~” refers to a very close estimate, while “-” refers to a slight overestimate, based on the granularity of company reporting. Estimates were conservatively withheld if deemed unreliable.

V. Semiconductors Cloud Shifts in the Balance of Power

Characteristic 1: Industry Dynamism and Unpredictability

As described in detail above, industry supply chains are hyper-globalized, perhaps unavoidably so. Logic chips are designed in the United States and manufactured in Taiwan using U.S. software, Dutch equipment using parts made in Germany and the U.S., and Japanese chemicals, photoresists, and photomasks. Korean firms control most of the memory market, while Europe is disproportionately strong in automotive chips and components. Everything is then assembled, tested, and packaged, typically across Southeast Asia. The industry is extremely interconnected; an Intel response to a Bureau of Industry and Security request for assistance identified that the company relies on over 16,000 suppliers.[48] Additional characteristics of the industry which make it especially dynamic are detailed below.

A. Demanding business cycle and intense competition

The semiconductor industry innovates rapidly and is marked by unforgiving competition. Companies invest tens of billions of dollars building foundries that, when successful, may not

[48] Greg S Slater, Letter to David Boylan, Defense Industrial Base Division, Office of Technology Evaluation, Bureau of Industry and Security, “Re: Docket No. 210310–0052: Intel Comments on Risks in the Semiconductor Manufacturing and Advanced Packaging Supply Chain (Federal Register Notice of March 15, 2021).” *Regulations.gov*, April 4, 2021.

generate positive cash flow until their fifth year.[49] Lower utilization rates often delay that positive cash flow generation even further. It also takes 12-24 weeks for an average chip to finish front-end production and then another 4-8 weeks on the back-end for packaging and testing.[50] In a winner-take-most industry, even slight mistakes and delays are devastating. While it takes months to produce a chip and many years to recoup an investment in a foundry, new chip generations have historically been released every 12-18 months, requiring facility upgrades and even entirely new facilities.[51] Falling behind in such a competitive industry is disastrous both financially and in terms of a firm's (and a country's) ability to keep pace with the rapid innovation and large budgets of leading players.

Intel's early, consistent dominance and recent struggles exemplify the uncertainty which characterizes the industry. In the early 2010s Intel was still dominant as both a manufacturer and as a supplier of PC processors and chips for data center servers.[52] The firm should have been well positioned to capitalize on the introduction of EUV lithography for more advanced nodes; Intel's Andy Grove and his massive bet on ASML lithography in the 1990s was crucial in finally delivering EUV technology.[53] However, Intel was slow to adopt EUV technology and suffered repeated delays in both 10nm and 7nm before temporarily abandoning manufacturing altogether.[54] Simultaneously, Intel's design business has lost market share as the needs of the booming data center processor market have increasingly been met by Nvidia and AMD's GPUs and even chips designed by cloud companies such as Google and Amazon.[55]

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[49] McKinsey Advanced Electronics Practice, "Semiconductor Design and Manufacturing: Achieving Leading-Edge Capabilities," McKinsey & Company, August 20, 2020.
[50] James Morra, "How Much Longer Will It Take to Fix the Chip Shortage?," *ElectronicDesign*, March 14, 2022.
[51] "Semiconductor Design and Manufacturing: Achieving Leading-Edge Capabilities."
[52] Miller, *235*.
[53] Don Clark, "The Tech Cold War's 'Most Complicated Machine' That's Out of China's Reach," *The New York Times*, July 4, 2021.
[54] Richard Waters, "Can Intel Become the Chip Champion the US Needs?," *The Financial Times*, April 13, 2023.
[55] Miller, 237-238.

Figure 8 displays key financial metrics for Intel from 2010-2022 compared to TSMC.[56] Intel's average Enterprise Value (EV) grew an average of 4.2% annually with a 3.2% annual revenue increase while TSMC's average EV grew 20.6% annually with a 15.7% annual revenue increase. TSMC generated a 17.1% annual increase in profits while Intel's profit has shrunk, although 2022 was an especially poor year. While the two business models are different, the table demonstrates the unpredictability and winner-take-most attributes of the industry.

($B, USD)												2010-2022	
Intel	**2010**	**2011**	**2012**	**2013**	**2014**	**...**	**2019**	**2020**	**2021**	**2022**	**4/24/2023**	**Growth**	**CAGR**
Avg. Enterprise Value	**99,642**	104,267	117,925	105,050	138,803		244,419	252,140	236,341	164,026	**137,359**	**65%**	**4.2%**
Revenue	43,623	53,999	53,341	52,708	55,870		71,965	77,867	79,024	63,054		**45%**	**3.1%**
Operating Income	15,588	17,477	14,638	12,531	15,642		22,428	23,876	22,082	2,336		**-85%**	**-14.6%**
Net Income	11,464	12,942	11,005	9,620	11,704		21,048	20,899	19,868	8,014		**-30%**	**-2.9%**
TSMC													
Avg. Enterprise Value	**45,463**	59,370	70,403	89,887	103,620		202,201	319,095	538,922	432,305	**406,498**	**851%**	**20.6%**
Revenue	13,257	14,493	17,111	20,054	25,117		34,602	45,266	56,643	75,969		**473%**	**15.7%**
Operating Income	5,030	4,804	6,132	7,055	9,774		12,184	19,151	23,203	37,653		**649%**	**18.3%**
Net Income	5,106	4,554	5,385	6,180	8,373		11,446	17,263	21,286	34,112		**568%**	**17.1%**

Note: Total shareholder return for two companies would also differ from the EV numbers because of dividends and share repurchases. New Taiwan Dollars are converted into USD at the appropriate historical rate.

B. Tight supply chains

The chip industry is highly interconnected and often hyper-customized; shortages for key providers can cripple the industry. Given the massive investments and maintenance required, lulls in production are inordinately expensive; not being able to run a single $20B foundry for days costs millions of dollars. The shortages of 2021 provide an excellent example of the potential for supply chain disruption: the automotive chip industry, which often uses more mature nodes, was hit when Fukushima again suffered a 7.1 earthquake and a Renesas plant was crippled in a fire a month later.[57] Taiwan also suffered a serious drought, and world supply plummeted further; as TSMC alone uses over 150,000 metric tons of water (often ultrapure water for cleaning, which is more water intensive) per day in Taiwan and UMC another ~32,000 per day (although they recycle ~87%), price increases and reduced supply/rationing of water

[56] Company filings, public market data.
[57] Stephanie Yang, "The Chip Shortage Is Bad. Taiwan's Drought Threatens to Make It Worse.," *The Wall Street Journal*, April 16, 2021.

damaged output significantly.[58] The unpredictable weather and periodic droughts of climate change will exacerbate this risk for typhoon water-reliant Taiwan, for America and its concentration of foundries in Texas and the arid West, and for water quantity- and quality-insecure China, whose foundries are in the especially insecure Northeast and East.[59] Simultaneous to the earthquakes and droughts in East Asia, Texas—normally also threatened by droughts—suffered a 2021 Arctic storm which crippled its energy grid, forcing producers such as Samsung, NXP, and Infineon to halt production with little notice; Samsung and NXP lost ~$300M and ~$100M in revenue that month, respectively, from wafer loss alone, in addition to likely significant repairs and fixed costs.[60] These shortages and a surge in demand cost the U.S. economy ~$240B in 2021, and led to global automotive companies losing ~$210B in 2021 revenue, as vehicles off the production line accumulated in factory parking lots waiting for chips.[61]

Critical rare material suppliers are also worldwide and disruptions can have unpredictable reverberations. Ukraine produces 70-80% of the world's neon, a critical component for lithography (45% of all neon demand), in the east of the country as a by-product of their older steel mills; both key Ukrainian producers had to shut down within months of the war, which may have serious long-term consequences for key lithography equipment.[62] Semiconductor supply chains are fragile without accounting for any potential conflict in the South China sea.

[58] Ibid.

[59] Emanuela Barbiroglio, "No Water No Microchips: What Is Happening In Taiwan?," *Forbes*, May 31, 2021; Elizabeth Wishnick, "Water With Your Chips? Semiconductors and Water Scarcity in China," *The Diplomat*, August 13, 2021.

[60] "Shutdown of Austin Fab during Freeze Cost Samsung at Least $268 Million," *Austin American-Statesman*, April 30, 2021.

[61] Omar Villafranca, "Chip Shortage Cost U.S. Economy Billions in 2021," *CBS News*, January 28, 2022.

[62] Lincoln Clark and Scott Jones, "Russia-Ukraine War: Impact on the Semiconductor Industry," KPMG, 2022.

C. Reliance on a handful of firms in a volatile industry

In several key areas, only one or two firms are able to produce at the cutting edge; TSMC and Samsung in manufacturing processors, Nvidia and AMD for GPUs, Intel and AMDs for PCs, Qualcomm for modems (perhaps soon Apple), ASML for EUV lithography, Cadence and Synopsys (and to some extent Mentor) for EDA and certain core IP, and ARM for processor cores. Numerous other firms dominate select niches in the supply chain for various types of chips and components. Any of these firms going out of business would have major ramifications for supply chains and likely would slow the pace of innovation, depending on the years of capital expenditures and R&D required for a new entrant to emerge and successfully compete. Given the massive investment required for industry leaders to maintain the rapid pace of innovation, poor capital allocation could easily result in ruin.

Figure 9 displays the top ten semiconductor companies (excluding Samsung and Broadcom, as they include substantial non-semiconductor businesses) by Enterprise Value (total value of the company), 2022 Revenue, and 2022 Operating Income. The top ten companies represent ~40% of the contribution from the top fifty firms in each category, and this weighting would be even larger if Samsung's and Broadcom's semiconductor businesses were separated. Non-logic companies like Texas Instruments and Analog Devices are referred to as "Analog" but are also IDMs. Data is from company filings and public market data.

USD $MM	2022		
Company	**Revenue**	**Type**	**Country**
TSMC	76,428	Foundry	Taiwan
Intel	63,054	IDM	United States
Qualcomm	42,958	Fabless	United States
SK Hynix	35,089	Memory	Korea
Micron	27,156	Memory	United States
NVIDIA	26,974	Fabless	United States
Applied Materials	26,253	Equipment	United States
AMD	23,601	Fabless	United States
ASE Technology	22,648	OSAT	Taiwan
ASML	22,372	Equipment	Netherlands
Top 10	**366,533**		
50 Top Firms	**1,007,016**		
% of Top 50	**36%**		

USD $MM, as of:	4/27/2023		
Company	**Enterprise Value**	**Type**	**Country**
NVIDIA	663,470	Fabless	United States
TSMC	393,670	Foundry	Taiwan
ASML	283,653	Fabless	United States
Texas Instruments	250,221	Memory	Korea
Intel	242,420	Equipment	Netherlands
Qualcomm	149,911	Analog	United States
AMD	135,927	Fabless	United States
Analog Devices	135,413	Fabless	United States
Applied Materials	134,836	IDM	United States
Lam Research	96,265	Analog	United States
Top 10	**2,485,786**		
50 Top Firms	**5,616,528**		
% of Top 50	**44%**		

USD $MM	2022			
Company	Op. Income	Margin	Type	Country
TSMC	37,880	50%	Foundry	Taiwan
Qualcomm	14,541	34%	Fabless	United States
Texas Instruments	10,095	50%	Analog	United States
Applied Materials	7,820	30%	Equipment	United States
ASML	6,869	31%	Equipment	Netherlands
Micron	6,839	25%	Memory	United States
Lam Research	6,049	32%	Equipment	United States
NVIDIA	5,577	21%	Fabless	United States
SK Hynix	5,355	15%	Memory	Korea
Tokyo Electron	4,733	29%	Equipment	Japan
Top 10	**105,758**	**32%**	**Average**	
50 Top Firms	**270,124**	**27%**	**Average**	
% of Top 50	**39%**			

D. Multiple-year foundry construction timelines

While making a chip takes months and a new generation becomes available every one-two years, it also takes around two years to construct and prepare a foundry, with total time from initial site deliberations to completion of production reaching up to five years.[63] This length affects the ability to reliably plan for the future for both companies and nations.

Figure 10 demonstrates how long it takes to create foundries. Especially in the U.S., the time from idea to production is far longer considering prospecting locations, negotiating with federal, state, and local governments, and navigating environmental reviews and regulations. Data can be found at the following footnote.[64]

Average # of Days from Fab Construction to Production

Country	1990-2000	2000-2010	2010-2020
United States	665	705	**918**
China	630	747	675
Taiwan	610	703	642

Source: World Fab Forecast, SEMI; Center for Security and Emerging Technology

Note: These numbers are not directly comparable, as different types and nodes vary in complexity, and Taiwan tends to construct especially large foundries.

[63] The National Semiconductor Economic Roadmap."
[64] John VerWey, "No Permits, No Fabs: The Importance of Regulatory Reform for Semiconductor Manufacturing," *Center for Security and Emerging Technology*, October 2021.

E. Geopolitical implications outside of U.S.-China

The highly competitive and capital-intensive nature of the industry, and the subsequent ability for firms to win or lose massive markets in only a few years, has major implications for geopolitics and can quickly create shifts in the distribution of capabilities.

The case of Japan in the 1980s demonstrates the inescapable connection between semiconductors and geopolitics, and how countries think deeply about their geopolitical importance even vis-à-vis their allies. In the 1980s, Japan became the world leader in memory chips, in part due to the relatively commoditized nature of this specific type of chip and firms' access to favorable *keiretsu* business group loans.[65] Their artificially low cost of capital and relatively inexpensive labor costs allowed them to undercut American producers and seize over 50% of global semiconductor production (a phenomenon later replicated by Korean companies, who would in a few decades replace the Japanese producers entirely).[66] Proximity and familiarity then led key Japanese memory leaders such as Toshiba (Mitsui Group), NEC (Sumitomo Group), and Hitachi (then part of DKB) to favor Japanese toolmakers such as Nikon and Cannon, who began to pull far ahead of rivals such as the now-defunct America GCA.[67] Ultimately, Japan fell behind due to a combination of U.S.-supported Korean successes in memory and Japan's access to artificially low financing discouraging competitive innovation, which led to the failure to recognize and invest in new NAND memory or the PC revolution.[68] Additionally, the United States, recognizing the importance of semiconductors in geopolitics, coerced Japan to sign a

[65] Paul Krugman, "Trade with Japan: Has the Door Opened Wider?," *National Bureau of Economic Research*, January 1991.
[66] Ibid; Miller, 88-89.
[67] Miller, 82, 95.
[68] Yoshitaka Okada, "Decline of the Japanese Semiconductor Industry: Institutional Restrictions and the Disintegration of Techno-Governance," in *Struggles for Survival* (Tokyo: Springer, 2006), 72;
Sumio Saruyama and Peng Xu, *Excess Capacity and Difficulty of Exit Evidence from Japan's Electronics Industry* (Singapore: Springer Verlag, 2021).

controversial 1986 agreement with questionable “anti-dumping” and “market-access” provisions.[69]

Japan during this period was a close ally of the United States and did not pose a military threat. However, semiconductors, even at that time, were critical enough for key Japanese leaders to openly voice the leverage that dominance granted them and advocate for its coercive use, and to generate a rash of both rational and irrational alarm in the U.S. Congress and military.[70] For instance, Sony co-founder Akio Morita and prominent Liberal Democratic Party (as well as other political groups) politician Shintaro Ishihara, former Governor of Tokyo and ~30-year member of the National Diet legislature, co-authored a book titled *The Japan that Can Say No*.[71] While Morita’s essays focused mostly on critiquing American business practices and demanding Japan embrace and assert its growing role in the world, Ishihara went further, explaining how Japan should exploit its nascent semiconductor success. He noted American military strength relied on Japanese chips for accuracy, and that “Japan is at least five years ahead of the U.S. in [then-critical 1-megabit memory chips] and the gap is widening”; Japanese chips were “central to military strength and therefore central to Japanese power.”[72] As the American military relied on these Japanese chips, Japan could wield immense leverage over America, and Ishihara even speculated Japan could provide advanced semiconductors to the U.S.S.R. Chips have long played a key role for militaries and in great power competition. Until the rise of China, however, the United States has never had a military rival that could approach its semiconductor expertise.

[69] Douglas A. Irwin, “The U.S.-Japan Semiconductor Trade Conflict,” *National Bureau of Economic Research*, 1994, 5-14.
[70] Johannes Eisele, “A Semiconducted Trade War,” *Foreign Policy*, July 1, 2019.
[71] Akio Morita and Ishihara Shintarō, *The Japan That Can Say No: Why Japan Will Be First Among Equals* (Simon & Schuster, 1992).
[72] Miller, 112.

The geopolitical importance of semiconductors and the unpredictability of the industry also shapes the actions of foreign firms and allies today, and leading firms are often considered critical for the economic and even military future of the state and are heavily subsidized. Samsung's revenue (albeit comprised of far more than semiconductors) often accounts for up to ~20% of the GDP of South Korea (sometimes called the "Republic of Samsung")[73] and has been known to wield considerable influence at the highest levels of Korean politics.[74] Taiwanese President Tsai Ing-wen has even noted that TSMC's dominance is a critical deterrent for Taiwan from Chinese invasion, which she labeled the island's "Silicon Shield."[75] The success of these industry leaders is a national security priority for their countries.

Characteristic 2: Dominance of the Commercial Market

<u>A. Relative size of the military market and military spending</u>

Semiconductor production and innovation is overwhelmingly driven by the commercial market, which is magnitudes larger than the market for chips for military devices. The United States military, by far the largest defense consumer, depends on both mature and cutting-edge semiconductors. Despite this, it accounts for only ~2% of the domestic market and less than 1% of global consumption, or under $3B.[76] Semiconductor investments are therefore tailored to the consumer end markets. In 2017, DARPA launched a $1.5 billion, five-year Electronics Resurgence Initiative for advanced chips, and bolstered it with a 2.0 initiative which includes

[73] Yoo-chul Kim, "Samsung Could Revive 'Control Tower' to Become More Agile," *The Korea Times*, October 17, 2022.
[74] Associated Press, "South Korea to Pardon Samsung's Lee, Other Corporate Giants," *NBC News*, August 12, 2022.
[75] Tsai Ing-wen, "Taiwan and the Fight for Democracy," *Foreign Affairs*, October 5, 2021.
[76] Graham Allison and Eric Schmidt, "Semiconductor Dependency Imperils American Security," Belfer Center for Science and International Affairs, June 20, 2022;
Michaela D. Platzer, John F. Sargent, and Karen M. Sutter, "Semiconductors: U.S. Industry, Global Competition, and Federal Policy," *Congressional Research Service*, October 26, 2020.

another $331M in the FY22 budget.[77] The entire DoD 2022 budget across all areas of research needs, not just semiconductors, included $2.8B for basic research, $6.9B for applied research, and $9.2B for advanced tech development.[78] The ten largest original equipment manufacturers (OEMs) alone, led by Apple, spent $234B on semiconductors in 2022. The four of those ten companies headquartered in China, Lenovo, BBK Electronics, Xiaomi, and Huawei, collectively spent $65.6B. Apple alone spent $67.1B on semiconductors in 2022. [79]

B. Lack of commercial investment for certain chips critical for militaries

Prime defense contractors, Taiwanese firms such as WIN, and some American companies such as SkyWater and Qorvo (although they are somewhat reliant on WIN and others in Taiwan[80]) manufacture some critical military-specific technologies, often using extra durable and reliant materials such as gallium arsenide (GaA) and gallium nitride (GaN).[81] Military-specific chips are often radio frequency integrated circuits (RF chips) that enable signals intelligence, military communications, radars, and jammers.[82] Many of these military chips are high cost and low volume, and their demand is too unpredictable for most chip companies, which is why the prime defense contractors are relied upon to manufacture many themselves.[83] The NSA had to

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[77] Mitch Ambrose, "FY22 Budget Outlook: Department of Defense," American Institute of Physics, December 2, 2021;
It should be noted that these investments are more for advancing basic research and applied research such as prototyping potential advancements, while chipmaker R&D is typically more focused on more near-term commercial viability.
[78] Will Thomas, "DOD Budget: FY22 Outcomes and FY23 Request," American Institute of Physics, June 15, 2022.
[79] Gartner Research, "Gartner Says Top 10 Semiconductor Buyers Decreased Chip Spending by 7.6% in 2022," February 6, 2023.
[80] Skyworks, "Skyworks Qualifies WIN Semiconductors for Gallium Arsenide Foundry Services," Skyworks Investor Relations, June 5, 2008.
[81] Eric Lee, "How Taiwan Underwrites the US Defense Industrial Complex," *The Diplomat*, November 9, 2021.
[82] Ibid.
[83] Alan Patterson, "Experts: U.S. Military Chip Supply Is Dangerously Low," *EE Times*, January 6, 2023.

abandon its chip fab in the 2000s; today, designing a chip can cost hundreds of millions of dollars and is prohibitively expensive for most government projects.[84]

C. Military reliance on commercially developed chips

Additionally, military systems are increasingly reliant on commercial off-the-shelf (COTS) chips, which are almost entirely manufactured in East Asia. Advanced fighters, missile defense systems, and advanced targeting, in addition to technologies such as supercomputers and AI, all depend on Taiwanese manufacturing.[85] America's "Trusted Foundry" program, which sources from U.S. foundries and implements rigorous security checks, currently accounts for only 2% of the devices used in military systems.[86] Deputy Secretary of Defense Kathleen Hicks noted that "approximately 98% of those commercial microelectronics that the DoD is so dependent on are assembled, packaged, and tested in Asia."[87]

There are no easy solutions. In 2020, the DoD phased in a new "zero trust" approach to sourcing microelectronics which let it source more heavily outside "trusted foundries," given the increasingly infeasible economics of the model. This approach assumes nothing the department buys is safe, and everything must be fully validated before deemed ready for use.[88] The scale and cost this undertaking requires underscores the security concerns around the chips needed to power modern military systems. As the Congressional Research Service noted, this dependency on chips built for the commercial market threatens "a reduced ability to influence technology

[84] Miller*,* 289.
[85] Sujai Shivakumar and Charles Wessner, "Semiconductors and National Defense: What Are the Stakes?," Center for Strategic and International Studies, June 8, 2022.
[86] John M. Donnelly, "Pentagon Races to Shore Up Supply Chain Security," Government Technology, April 9, 2021.
[87] Alan Patterson, "Intel Foundry's 'No. 1' Customer—U.S. DoD—Targets GAA," *EE Times*, September 29, 2022.
[88] C. Todd Lopez, "DOD Adopts 'Zero Trust' Approach to Buying Microelectronics," U.S. Department of Defense, May 19, 2020.

development and a loss of unique access to state-of-the-art technologies."[89] However, the pace of chip innovation would be exponentially slower without buying COTS developed with R&D and capital expenditures justified by the commercial end-market.

D. Divergence of military and civilian needs

The commercial market may also be increasingly diverging from military needs. Historically, node improvements, led initially by Intel and now by TSMC, have led to "general-purpose" advances in capabilities across computing. Today, the world of such general-purpose improvements may be ending, and not simply because the industry may be reaching the physical limits of placing transistors.[90] Increasingly, chips made for specific purposes are emerging at the forefront of certain critical processes. For instance, Nvidia's GPUs are designed specifically for graphics and running AI workloads, and Google and Amazon design cutting-edge chips specifically for their cloud servers.[91] This trend may be positive for innovation and healthy competition in the chip industry, but could be a major issue for the American military as it becomes increasingly difficult to adopt best-of-breed commercial innovations for military needs. While the American military can source from SkyWater (in insufficient quantities; the entire company generates under $250M of revenue) for reliable 90nm and 130nm chips for certain conventional weapons, no trusted foundry offers 5nm.[92] GlobalFoundries, which operates trusted foundries, famously abandoned its 7nm ambitions (which would have required massive investments, including EUV machines) in 2018 to focus on expanding capacity in slightly more

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[89] John M. Donnelly, "Special Report: Microchip Security Continues to Confound Pentagon," Roll Call, April 6, 2021.
[90] Neil C. Thompson and Svenja Spanuth, *MIT Initiative on the Digital Economy Research Brief* 1 (2019).
[91] Miller, 349-350.
[92] Patterson, "Experts: U.S. Military Chip Supply Is Dangerously Low."

mature nodes, a pivot which has played out brilliantly for the firm.[93] Also in 2018, Intel ceased its struggling contract manufacturing operations before restarting them slowly and then in earnest by 2021, although it remains behind TSMC and Samsung.[94] America therefore must source its most important, cutting-edge chips for F-35 stealth planes and other critical systems from Taiwan. However, American policy and the threat of espionage prevent America from customizing chips overseas. This restriction forces top American weapons systems to be powered by Field-Programmable Gate Array chips (FPGAs), as they can be produced in Taiwan but configured domestically, without revealing any sensitive information about weapons systems.[95] DARPA and the DoD have been instrumental in producing some early investments and standards for "chiplets" (many smaller "chiplets" are combined on a singular package) which the military and now the commercial market are utilizing.[96] However, many functions are increasingly best served by purpose-built ASICs built by TSMC, which the military cannot fully utilize because of the level of disclosures needed.[97] Hypothetical cutting-edge manufacturing capacity in America is increasingly more valuable to the military than is identical capacity in allied countries, even in perfect peacetime conditions.[98] This trend may accelerate in the future, and it is not clear the extent to which the American military will suffer without a cutting-edge foundry in America.

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[93] Steven Leibson, "GlobalFoundries Chases Down a Different Semiconductor Rabbit Hole," Electrical Engineering Journal, July 5, 2022.
[94] Ting-Fang Cheng and Lauly Lu, "Intel Challenges Taiwan's TSMC in Chip Foundry Business," *Nikkei Asia*, March 24, 2021.
[95] Patterson, "Experts: U.S. Military Chip Supply Is Dangerously Low."
[96] Mark LaPedus, "Expanding Advanced Packaging Production In The U.S.," Semiconductor Engineering, January 5, 2022.
[97] Patterson, "Experts: U.S. Military Chip Supply Is Dangerously Low."
[98] Ibid.

E. Non-state actor risk

China has successfully used its economic power and massive consumer base to initiate coerced or voluntary technology transfers from American and foreign firms, highlighting the uncertainty of relying on non-state actors to develop critical technology. As one semiconductor executive noted to a White House official, their "fundamental problem is that [their] number one customer is [their] number one competitor."[99] There are numerous examples of China obtaining IP from the Taiwanese and South Korean foundries on the mainland mentioned above, although the firms are careful to only manufacture lagging-edge facilities in China.[100] Some policymakers and analysts in China actually disapprove of these investments, arguing it crowds out domestic manufacturers who could eventually invest and innovate to reach the cutting edge.[101] As many as half of all chips manufactured in China before the export ban were produced by non-Chinese firms such as TSMC, Samsung, and SK Hynix.[102]

IBM, one of the U.S. government's most trusted partners, seems to have voluntarily shared vital technology with the Chinese government. The Edward Snowden leaks of 2013 had revealed the NSA's PRISM program, which collected internet communications from U.S. internet companies, including IBM; Snowden's documents suggested the NSA was using IBM and others to hack into network infrastructure in Hong Kong and part of the mainland.[103] The next quarter, IBM's China sales dropped 22%, including 40% in hardware, as China investigated and initiated a renewed localization effort alongside probes of American technology providers.[104]

[99] Miller, 301.
[100] Gina Keating, "California Jury Finds SMIC Stole Trade Secrets," *Reuters*, November 3, 2008.
[101] Xin Zhao and Pan Che, "Why Has TSMC's Nanjing Expansion Plan Stirred up a Hornets' Nest in Beijing and Taipei?," *South China Morning Post*, May 1, 2021.
[102] James Andrew Lewis, "China's Pursuit of Semiconductor Independence," Center for Strategic and International Studies, January 17, 2019.
[103] Lance Whitney, "NSA Whistleblower: U.S Has Been Hacking into China, Hong Kong," *CNET*, June 13, 2013.
[104] Matthew Miller, "In China, U.S. Tech Firms Weigh 'Snowden Effect'," *Reuters*, January 21, 2014.

IBM then embarked on a Chinese public relations blitz, with CEO Ginni Rometty repeatedly visiting Beijing to meet with Premier Li Keqiang and Vice Premier and chip czar Ma Kai and attend the 2015 China Development Forum.[105] At that time, IBM had lost its position designing chips for corporate servers to Intel and AMD's x86 designs.[106] IBM's solution to being squeezed out of China and the data server market was to open its chip technology to China and, in the words of Rometty herself, help "create a new and vibrant ecosystem of Chinese companies producing homegrown computer systems for the local and international markets"; IBM seems to have traded technology for market access.[107]

AMD has been accused of transferring even more sensitive technology despite not clearly breaking any laws. While the company has undergone a remarkable turnaround in recent years, in 2016 its future seemed uncertain, losing its lagging PC and data center market share to Intel and running low on cash.[108] In addition to selling an ATP foundry to a Chinese entity,[109] in February of 2016, AMD signed a joint venture (JV) with an entity called "THATIC" (majority-owned by Chinese supercomputer developer Sugon Information Industry Co.), licensing AMD's x86 processor technology for $293M plus likely substantial royalties.[110] AMD did not submit the JV to the Committee on Foreign Investment in the U.S. (Cfius); instead, AMD removed certain encryption protocols to comply with export controls, and the Commerce Department approved the JV.[111] However, it remains debated whether AMD retained control of its intellectual property, especially as AMD retained control over the IP-side of the dual JV, while Sugon's

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[105] Miller, 255-256.
[106] Ibid, 256.
[107] Paul Mozur, "IBM Venture With China Stirs Concerns," *The New York Times*, April 19, 2015.
[108] Miller, 258.
[109] Kate O'Keeffe and Brian Spegele, "How a Big U.S. Chip Maker Gave China the 'Keys to the Kingdom,'" *The Wall Street Journal*, June 27, 2019.
[110] Eliza Gkritsi, "AMD Claims No Wrongdoing in Passing US Chip Tech to China," TechNode, July 1, 2019.
[111] O'Keefe and Spegele.

control over the design facilitated their claim to Chinese subsidies related to indigenous innovation.[112] Sugon, whose website in December 2016 noted "making contributions to China's national defense and security is the fundamental mission of Sugon," attained benchmarking results 2x higher than the then-#1 ranked US-based Summit supercomputer in 2019 before being placed on the Entity List.[113] As noted by Commerce Secretary Gina Raimondo, supercomputers are often used to help design and improve "nuclear weapons and hypersonic weapons."[114]

IP theft has also remained a constant threat; in the first four months of 2023 alone, seven former Samsung employees were jailed for stealing blueprints and components lists for semiconductor cleaning equipment and transferring them to China.[115] ASML has suffered two data transfers from former employees over the same time period.[116] However, the company likely had sectioned off some of its key data from its China offices, where both employees were based.

Firms, especially those in financial distress, have been willing to license technology to access China's lucrative market, especially when they are not the clear leader or the technology is in a non-core business line. While JVs such as AMD-THATIC/Sugon are likely no longer possible, there remains the risk of forced or even willing technology transfer, especially for non-U.S. firms. The critical role of non-state actors which rely on global sales in producing semiconductors creates further unpredictability.

Characteristic 3: Uncertainty of Identifying and Securing Military Needs

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112 Ibid.

113 Tiffany Trader, "Chinese Company Sugon Placed on US 'Entity List' After Strong Showing at International Supercomputing Conference," *HPCWire*, June 26, 2019.

114 "Commerce Adds Seven Chinese Supercomputing Entities to Entity List for Their Support to China's Military Modernization, and Other Destabilizing Efforts," *U.S. Department of Commerce*, April 8, 2021.

115 Jiyoung Sohn, "Leaking Chip Secrets to China Results in Jail Terms for Ex-Samsung Employees," *The Wall Street Journal*, February 21, 2023.

116 Jordan Robertson, Cagan Koc, and Chris Strohm, "Ex-ASML Employee Accused of Data Theft Is Being Probed for Ties to China," *Bloomberg*, February 24, 2023.

A. Uncertain future technological capabilities of chips and end uses

The dynamism and complexity of the industry as well as the dominance of the commercial market over the military make planning and assessing future military capabilities extremely challenging. With militaries increasingly relying on commercial-off-the-shelf (COTS) components, the future of reliable semiconductor procurement depends on the success of a handful of firms which cater to commercial customers that rely on thousands of suppliers across the world.

Beyond the high uncertainty of success for existing and future domestic producers, the technological progress and direction of the industry and specific chipmakers, especially as they relate to military uses, is even less knowable. For example, Intel, derived most of its business from memory in its early decades, but by the 1980s, Japan was able to undercut memory prices and drive Intel out of the market; Grove then bet everything on a small microprocessor market.[117] He laid off 25% of his workforce, shuttering facilities and surrendering the company's memory crown jewel to the Japanese and rebuilding Intel into the largest semiconductor firm for many years.[118] Intel's decision to pivot drastically improved global computing power and its dominance of microprocessors played a key role in ending Japanese semiconductor dominance. Such existential crises and complete reinventions are common in the industry.

These reinventions continue to shape the progress of chipmaking. Nvidia, the world leader in GPUs, successfully reinvented itself several times, from making chips primarily for video game graphics to becoming possibly the most important artificial intelligence company.[119] Visionary CEO Jensen Huang reportedly spent $10B and a decade on Nvidia's CUDA software for coding

[117] Elizabeth Corcoran, "Reinventing INTEL," *Forbes*, May 3, 1999.
[118] Miller, 126.
[119] Katie Tarasov, "Nvidia CEO Jensen Huang's Big Bet on A.I. Is Paying off as His Core Technology Powers ChatGPT," *CNBC*, March 7, 2023.

before the market began to appreciate its future value for uses like AI and data centers.[120] Without Huang, today's artificial intelligence capabilities would likely be vastly inferior.

Similarly, EUV lithography, which prints designs in silicon using extreme ultraviolet light, took over twenty years to come to market amid great uncertainty, supported by multiple semiconductor giants, America's national labs, billions of dollars, and highly-technical parts from across the world.[121] In 1992, ASML was struggling and Phillips, which owned them at the time, reportedly tried to sell ASML for $60M to now-defunct American lithography firm SVG.[122] Today, a single EUV machine costs $150M, and the firm is worth ~$245B in 2023.[123] San Francisco-based Cymer had to develop a system to shoot a 0.03mm tin ball in a vacuum at 200mph and strike the ball twice at half a million degrees Kelvin 50,000 times per second with a 50,000 lasers to produce EUV light.[124] German precision tooling company Trumpf created an ultra-powerful carbon dioxide laser cooled with fans suspended in air by magnets;[125] the laser alone has 457,329 component parts.[126] German optics company Zeiss then created ultra-smooth mirrors, alternating layers of molybdenum and silicon each a couple nanometers thick. In total, ASML produced only ~15% of the machine itself, sourcing hundreds of thousands of custom-made from thousands of global suppliers.[127] While ASML has acquired several of its key suppliers, such as Cymer, the intricacy remains and the company relies on more than 5,000 specialized suppliers.[128] One study estimates that ~32% of suppliers are from the Netherlands,

[120] Don Clark, "Why a 24-Year-Old Chipmaker Is One of Tech's Hot Prospects," *The New York Times*, September 1, 2017.
[121] Cagan Koc, Ian King, and Jillian Deutsch, "ASML, Europe's Most Valuable Tech Firm, Is at the Heart of the US-China Chip War," *Bloomberg*, April 26, 2023.
[122] Craig Addison, "Losing Lithography: How the US Invented, Then Lost, a Critical Chipmaking Process," Semiwiki, December 10, 2021.
[123] Public market data as of April 2023.
[124] Clive Thompson, "Inside the Machine That Saved Moore's Law," *MIT Technology Review*, October 27, 2021.
[125] Miller, 228.
[126] TRUMPF Group, "TRUMPF Laser Amplifier," accessed April 20, 2023.
[127] Miller, 228.
[128] Varas et al, 30.

27% are from North America, 27% are from Asia, and 14% are from the rest of Europe, the Middle East, and Africa; EUV lithography machine production remains a delicate, global undertaking which unavoidably relies on intact, complex supply chains.[129] Despite the constant questioning of its feasibility for decades, EUV today is responsible for nearly every 7nm chip and every 5nm and below chip in existence.

The success of Nvidia's CUDA-powered chips used in AI and ASML's EUV lithography were highly uncertain and even discarded as failures by much of the industry. Today, they are clearly two of the most important innovations of the past decade, and both have major military implications. The two technologies have also been at the forefront of U.S. export restrictions; the Trump administration successfully prevented ASML from selling a EUV lithography machine to China (likely SMIC) as early as 2018,[130] and Nvidia was restricted in 2022 from selling its most powerful chips to China because of their use in AI and supercomputers.[131]

Industry leaders and top scientists, much less political and military leaders, cannot predict future semiconductor innovations or where they will be invented and implemented. EUV lithography could have been invented in Japan, where Canon and Nikon were previously lithography leaders, or in the U.S., where lithography was invented and which led the world before the Japanese pulled ahead in the 1980s.[132] The next technology with the impact of EUV or Nvidia's AI chips could be developed and implemented in America, in Taiwan, or in China.

The likelihood that one of these next-generation technology breakthroughs comes from China increases every year. China is investing heavily in potential "leapfrog" technologies, such

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[129] Ibid.
[130] Alexandra Alper, Toby Sterling, and Stephen Nellis, "Trump Administration Pressed Dutch Hard to Cancel China Chip-Equipment Sale: Sources," *Reuters*, January 6, 2020.
[131] Stephen Nellis and Jane Lee, "U.S. Officials Order Nvidia to Halt Sales of Top AI Chips to China," *Reuters*, September 1, 2022.
[132] Addison.

as wide-bandgap (WBG) SiC and GaN chips[133] and RISC-V source architecture (a powerful open-source alternative to x86 Intel-led PC/server architecture and to the U.K.'s ARM-led smartphone design architecture).[134] Militaries face great uncertainty concerning future chip developments and their application for military systems, as well as concerns about which country will ultimately develop them.

B. Challenges in procurement

This great uncertainty surrounding future developments, as well as the dynamism and complexity of the industry, makes acquiring and stockpiling cutting-edge chips extremely difficult. With a new chip generation historically coming out every 12-18 months, stockpiled "cutting-edge" chips become quickly outdated.[135] Foundries also have considerable incentive to prioritize commercial customers, as their demand is more reliable and the volume is larger. Foundries such as TSMC, Samsung, and Intel compete to win and secure the order of each generation of chip design. In 2022, Apple paid TSMC ~$17.3B, generating 23% of the firm's total sales; TSMC will prioritize meeting Apple's capacity demands and specifications.[136] In February 2023, it was reported that Apple had booked the entire first wave of N3 (TSMC's first 3nm-class node) production, while other designers such as Qualcomm and Nvidia will wait for the second generation of TSMC's 3nm tech, which is expected to begin mass production at the end of 2023.[137] TSMC has reported their 3nm chips deliver 15% higher performance than 5nm,

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[133] Junko Yoshida , "SiC in China: 'Poster Child of the Decoupling Era,'" Yole Group, December 7, 2022.
[134] Annie Cao, "Tech War: China Bets on RISC-V Chips to Escape the Shackles of US Tech Export Restrictions," *South China Morning Post*, December 2, 2022.
[135] "Semiconductor Design and Manufacturing: Achieving Leading-Edge Capabilities."
[136] The Taipei Times, "TSMC Customer Billed NT$529bn," March 7, 2023.
[137] Yujuan Chen, "台積電N3E將上陣　蘋果下好下滿　高通、聯發科緊追 ('TSMC's N3E Will Go to Battle, Apple Will Play Well, Qualcomm and MediaTek Will Follow Closely')," *DigiTimes*, February 21, 2023, https://www.digitimes.com.tw/tech/dt/n/shwnws.asp?id=0000657347_VRL4370I3QN3C887ABXNO

while consuming 30-35% less power.[138] However, TSMC is also reportedly struggling to raise 3nm yields, threatening the ability to manufacture Apple's A17 Bionic and M3 chips.[139] TSMC and Samsung are expected to enter mass production for their 2nm layout in 2025 (note that TSMC's new Arizona facilities will not produce 4nm chips until 2024 at the earliest, and will not produce 3nm chips until 2026 at the earliest[140]).[141] It may take years for the American military to acquire 3nm-class chips and then configure and test them.

The above represent only one facet of the military's procurement struggles. While F-35s and supercomputers benefit tremendously from cutting-edge chips, militaries also depend on reliable parts considered ancient by commercial standards. America's aging military equipment constantly needs maintenance and replacement parts, including semiconductors made decades ago. For chips which power engine control for tanks, for instance, chip size and incremental processing power is irrelevant; what matters is tested durability, especially in intense conditions.[142] However, even foundries which produce chips considered "mature" by 2023 standards are not able to maintain the relatively ancient facilities to produce the ancient chips needed by the military. Additionally, there are thousands of types and specifications of chips the military uses and might need to replace; it is very difficult to manage such stockpiles, especially as the future ability to replenish them is rapidly diminishing. As stated previously, manufacturing

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[138] Majeed Ahmad, "TSMC's 3-Nm Progress Report: Better than Expected," EDN Asia, March 14, 2023.
[139] Omar Sohail, "TSMC Is Unable To Meet Apple's 3nm Chip Demand For The A17 Bionic And M3," Wccftech, April 26, 2023.
[140] Emma Kinery, "TSMC to up Arizona Investment to $40 Billion with Second Semiconductor Chip Plant," *CNBC*, December 6, 2022.
[141] Atkinson, "台積電 2 奈米 2025 年按時推出，之後就是 N2P 製程 ('TSMC's 2nm Will Be Launched on Time in 2025, Followed by N2P Process')," 科技新报 *("Science and Technology News")*, April 10, 2023, https://technews.tw/2023/04/10/tsmcs-2nm-process-is-on-track-for-2025/?fbclid=IwAR2C04ZI52mBa1sm4wXiNbHcU6rSa0r0xV8SeNQLJVeGslW8aOmPFnFbin8
[142] Patterson, "Experts: U.S. Military Chip Supply Is Dangerously Low."

or even designing semiconductors without a large commercial market paying upfront costs and high maintenance is extraordinarily expensive, to the point of being untenable.

C. Disappearance of American manufacturing and the challenges of industrial policy

American manufacturing share by location of foundry capacity (rather than company headquarters) has declined from 37% in the 1990s to around 12% in 2022.[143] In terms of U.S. and global innovation, this may be a positive development, and even unavoidable. World-leading American companies like Nvidia and Qualcomm have benefited greatly from avoiding the added complexity and start-up costs of manufacturing chips.[144] Today, perhaps because of "losing manufacturing," America still contributes more value to the semiconductor industry than any other country, whether measured by location of facilities or by company headquarters.[145] Building cutting-edge foundries in Taiwan is a highly complex and expensive undertaking; doing so in America is near impossible by comparison.

The challenges of American manufacturing are seen in recent government-led efforts to onshore production, such as SMC's 2021 and 2022 commitments to invest at least $40B in two subsidized foundries in Arizona.[146] The company estimates manufacturing costs are at least 1.5-2x greater than in Taiwan, driven by higher costs for construction and labor, as well as lack of initial subsidy payout.[147] America also faces a serious shortfall in skilled personnel, with Commerce Secretary Raimondo estimating a shortage of 100,000 in the next few years.[148] The

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143 President's Council of Advisors on Science and Technology, "Report to the President: Revitalizing the U.S. Semiconductor Ecosystem," 12.
144 Miller, 213.
145 "2022 State of the Semiconductor Industry Report."
146 Dylan Martin, " TSMC Triples Spending on Arizona Advanced Chip Site with Extra 3nm Fab," *The Register* , December 6, 2022.
147 Taijing Wu, "Taiwan Chip Pioneer Warns US Plans Will Boost Costs," *AP News*, March 16, 2023.
148 Eric Martin, "US Urges College, Chip-Firm Partnerships as It Faces Technician Shortfall," *Bloomberg*, April 18, 2023.

president of industry association SEMI estimated the U.S. may need 500,000-600,000 more skilled workers by 2030 to achieve success.[149] A large culture clash has already become evident,[150] with U.S. engineers decrying a "military culture" and Taiwanese engineers calling their American counterparts a "group of giant babies."[151] These challenges are in part why TSMC Founder Morris Chang, who was a key leader at Texas Instruments from 1958-1983 before inventing the concept of outsourced manufacturing with TSMC, stated in 2022 that the U.S.'s attempt to increase onshore semiconductor manufacturing through the CHIPS Act is "a wasteful and expensive exercise in futility."[152] The 91-year-old Taiwanese national hero also stated that the TSMC fab occurred largely "at the urging of the U.S. government" and does not seem overly optimistic about its prospects.[153]

Suppliers who invested in facilities near the TSMC facilities in Phoenix, Arizona face perhaps greater difficulties. Chemical supplier Chang Chun, the biggest supplier of wet chemicals and litho-chemicals for semiconductors in Taiwan, opened a $300M facility nearby in Arizona.[154] The company has reported costs ten times higher than in Taiwan, due to U.S. regulations and building permits and insufficient supply of production materials.[155] Direct funding is limited to capital expenditures, typically subsidizing 5-15% of a project's initial cost, and likely capped at 35%.[156] These subsidies do not sufficiently cover higher construction costs,

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[149] Ibid.
[150]Alan Patterson, "TSMC's Culture Clash at Arizona Fab," *EE Times*, March 1, 2023.
[151] Ramish Zafar, "TSMC's U.S. Engineers Are 'Babies' Say Taiwanese After The Former Leave For America," Wccftech, November 6, 2022.
[152] Monica Chen and Ines Lin, "TSMC Reiterates 30% Growth Goal for 2022, Citing Surging Demand from Auto, HPC Sectors," *DigiTimes Asia*, June 8, 2022.
[153] Mike Rogoway, "TSMC's Morris Chang Explains WaferTech's Failure in Camas, Calls Push for U.S. Chip Revival an 'Exercise in Futility," *The Oregonian*, April 21, 2022.
[154] "Chang Chun Arizona Breaks Ground on Manufacturing Facility in Casa Grande," October 20, 2022. Arizona Commerce Authority.
[155] John Liu and Paul Mozar, "Inside Taiwanese Chip Giant, a U.S. Expansion Stokes Tensions," *The New York Times*, February 22, 2023.
[156] David Shepardson, "Biden to Require Chips Companies Winning Subsidies to Share Excess Profits," *Reuters*, March 1, 2023.

much less the higher production cost of U.S. labor and other regulations. These higher costs will either make the Arizona-produced chips far more expensive and uncompetitive, or they will require further massive subsidy by the American taxpayer. At any meaningful scale, such subsidies become fiscally and politically impossible.

Even if this massive investment becomes a resounding success, it would do little to increase American manufacturing output without major additional expansions. The $40B fabs will reportedly initially produce 600,000 wafers per year, compared to 24 million per year in Taiwan, and less than 3% of the company's total output.[157] Additionally, by the time these foundries enter production, TSMC will be producing more advanced nodes in Taiwan.[158]

Manufacturing cutting-edge chips in America is an intrinsically difficult task; some suggest a bevy of unrelated and unreasonable objectives are making it impossible.[159] For instance, recipients with over $150M in direct funding (recall TSMC is investing $40B at around double the cost of building a similar facility in Taiwan, and American construction will take far longer, delaying returns) "will be required to share with the U.S. government a portion of any cash flows or returns that exceed the applicant's projections by an agreed-upon threshold."[160] Semiconductor firms invest billions of dollars up front which are only justified from profits far into the future, and routinely suffer billions of dollars of net losses in cyclical industry downswings; without the ability to capture the potential upside in good years, the manufacturing business model simply does not work. The government has also injected other policy objectives

[157] Martin, " TSMC Triples Spending on Arizona Advanced Chip Site with Extra 3nm Fab."
[158] Kinery, "TSMC to up Arizona Investment to $40 Billion with Second Semiconductor Chip Plant."
[159] Steven Rattner, "Red Tape Threatens U.S. Efforts to Revive Chipmaking," *The Washington Post*, March 22, 2023.
[160]Shepardson, "Biden to Require Chips Companies Winning Subsidies to Share Excess Profits."

into the CHIPS Act, although the White House argues they are key for workforce development.[161]

Requirements include:[162]

- "An equity strategy…to create equitable work force pathways for economically disadvantaged individuals" which should include " new pipelines for workers, including…economically disadvantaged individuals [to] promote diversity, equity, inclusion and accessibility"
- "[A] plan to include women and other economically disadvantaged individuals in the construction industry"
- "Strongly encourage[] project labor agreements"
- "Access to child care for facility and construction workers"
- "Establishing delivery schedules for subcontractors that encourage participation by small, minority-owned, veteran-owned and women-owned businesses."
- Requirements for "a climate and environment responsibility plan"
- Community investments in areas like transit, affordable housing and schools

Then there are the national, state, and local environmental reviews. The National Environmental Policy Act (NEPA), which applies to federally-funded projects, takes an average of 4.5 years to complete. Reviews and permits for agencies such as the Arizona Department of Environmental Equality (under the Clean Air Act, Resource Conservation and Recovery Act, and Clean Water Act) take 12-18 months for larger fab projects.[163] Certainly, foundries have a very large environmental impact, consuming massive amounts of water and electricity and producing major hazardous waste.[164] However, it is impossible, both financially and technically, to produce cutting-edge chips if it takes years to clear environmental reviews and receive permits.

Even if TSMC's Arizona plants are a resounding success and reach sufficient outputs and yield, problems for the American military still remain. TSMC has no advanced packaging

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[161] "Experts Agree: Chips Manufacturing and National Security Bolstered by Childcare," March 8, 2023, The White House Briefing Room.
[162] Ezra Klein, "The Problem With Everything-Bagel Liberalism," *The New York Times*, April 2, 2023.
[163] Hideki Uno and Benjamin Glanz, "What Environmental Regulations Mean for Fab Construction," Center for Strategic & International Studies, June 11, 2022.
[164] Pádraig Belton, "The Computer Chip Industry Has a Dirty Climate Secret," *The Guardian*, September 18, 2021.

facility in the United States, and will likely need to send its Arizona output back to its own advanced packaging facilities in Taiwan, or rely on limited American OSAT; especially as Taiwan is not eager to transfer to the U.S. the benefits of serving as the premier industrial cluster of semiconductors, there is a large incentive to avoid building TSMC advanced packaging facilities in the U.S.[165] TSMC's fabs are also unlikely to serve the Trusted Foundry program given their focus on large customers, cultural barriers, and security concerns.[166] The American military's best hope of a cutting-edge trusted foundry remains a revitalized Intel Foundry Services, which recently won an initial $250M DoD contract for chip design and development.[167] As described previously, Intel's manufacturing resurgence is far from guaranteed, given their well-documented struggles of the past decade and the dominance of TSMC and Samsung. Even if Intel continues to struggle financially and technologically, however, the DoD will still benefit from more advanced Trusted Foundries; for some applications, slightly lagging ASICs manufactured by Intel might be preferred to the cutting-edge but general-purpose Field-Programmable Gate Arrays the DoD currently has to source from TSMC (to avoid sending configuration details overseas).[168]

D. Potential conflict with American allies

The national security importance of semiconductors for American allies makes United States industrial policy an especially sensitive operation. Two of the most significant acts of industrial policy in decades highlight this risk. In August 2022, the U.S. passed the CHIPS Act, including $39B in subsidies, $13B of investment in research, and a 25% tax credit for American-

[165] LaPedus, "Expanding Advanced Packaging Production In The U.S."
[166] Patterson, "Experts: U.S. Military Chip Supply Is Dangerously Low."
[167] Patterson, "Intel Foundry's 'No. 1' Customer—U.S. DoD—Targets GAA."
[168] Patterson, "Experts: U.S. Military Chip Supply Is Dangerously Low."

based manufacturing, with President Biden declaring "the future of the chip industry is going to be made in America."[169] Two months later, the Biden administration began a series of gradually-tightening restrictions on exporting cutting-edge semiconductor technology to China, and has since secured promises of restrictions from Japan and the Netherlands, as well as the cooperation of TSMC.[170] The United States is effectively seeking to transfer market share from allies such as Taiwan and South Korea while pressuring them to not sell to their biggest customer. That biggest customer, China, is also spending hundreds of billions on boosting Chinese capabilities in an attempt to reduce its dependence on foreign chips, including dominant Taiwanese and Korean manufacturing. United States export restrictions and domestic manufacturing are impossible without the participation and goodwill of allies and their market-leading national champions. American industrial policy in semiconductors must be handled delicately.

U.S. policy may be exacerbating this issue. The U.S. government is demanding companies applying for subsidies submit detailed financial projections with expected cash flows, including detailed profitability indicators such as wafer type, expected wafer yield, selling prices in the first year of production, production volume for each year, cost structure, and changes in prices.[171] Such requirements are supposedly for tracking viability and capturing potential "excess profits," the latter of which is a questionable goal when the importance of establishing domestic manufacturing is so great and the risks of failure so high. More critically, such information is highly revealing and closely guarded, and, especially in the commoditized memory industry, tantamount to the most critical company secrets.[172] If such trade secrets were somehow to fall

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[169] The Economist, "Taiwan's Dominance of the Chip Industry Makes It More Important," March 6, 2023.
[170] Nicholas Gordon, "Biden's Efforts to Starve China of Chips Are Rewriting the Rules of Global Trade–and Even U.S. Allies Are Balking at the Upheaval," *Fortune*, December 17, 2022.
[171] Min-hee Jung, "Korean Semiconductor Industry Calls US Demands 'Hardly Acceptable,'" *Business Korea*, March 29, 2023;
[172] In-Seol Jeong and Jeong-Soo Hwang, "Samsung, SK Hynix Asked to Swallow Tough Pill over US CHIPS Act," *The Korea Economic Daily*, March 28, 2023.

into the hands of the U.S.-based Micron or Intel, foreign companies and their countries would suffer enormously.[173]

Another point of possible tension is the manufacturing facilities companies such as TSMC, Samsung, and SK Hynix operate in China. These facilities are typically kept slightly behind the cutting-edge so as to avoid IP transfer (TSMC's Chinese facilities' most advanced chips are 28nm and 16nm), but nonetheless represent major investments and assets for these three key companies.[174] Thus far, the U.S. commerce department has granted one-year exceptions to supply equipment needed for these facilities without applying for licenses; the status of these exceptions beyond their expiration in October 2023 is uncertain, and firms stand to lose billions of dollars each.[175]

E. Effect of export controls and further conflict with allies

The other prong of the Biden administration's semiconductor strategy is export bans, which now pose an added, major challenge to Chinese semiconductor production and self-sufficiency. **See Appendix 2** for an analysis of the weaknesses and relative strengths of Chinese chipmaking. However, they also risk further alienating American allies and their companies. The Biden administration's 2022 and 2023 restrictions outstrip previous bans significantly, banning exports of all advanced SME and the most advanced chips (such as NVIDIA and AMD GPUs) made by America and its allies to all Chinese companies, rather than those linked to the Chinese

[173] Hae-Lee Park, Suk-Hyun Ko, and Jae-Lim Lee, "CHIPS Act Money May Not Be Worth the Trouble," *Korea JoongAng Daily*, March 29, 2023.
[174] Pan Che, "TSMC Gets One-Year Equipment Waiver for Mainland China Chip Plant, Easing the Blow from New US Restrictions," *South China Morning Post*, October 12, 2022.
[175] Jiyoung Sohn, "SK Hynix Gets One-Year Reprieve From U.S. Chip Restrictions on China," *The Wall Street Journal*, October 12, 2022.

military.[176] These broader bans come in part as a result of heightened (although somewhat misconstrued) concern over China's drive for "military-civil fusion" (MCF).[177] While MCF is often misconstrued, it is undeniable that the PLA easily obtained restricted cutting-edge chips from commercial Chinese buyers.[178] Regardless, these sanctions, which are accompanied by restrictions on American citizens and green card holders working for Chinese chip companies, have prompted firms including Texas Instruments, Marvell, and Micron to close their production and R&D teams in China.[179] Chinese SME leader AMEC will potentially be hit especially hard by these restrictions, as the flagship firm was founded by the highly-successful naturalized U.S. citizen Gerald Yin Zhiyao; many U.S. citizens, including dozens of Chinese chip executives, face uncertain futures caught between the two powers.[180]

The bans have thus far had a major effect on many exports, despite confusion concerning the requirements. According to data from the fourth quarter of 2022 (4Q22): Japanese exports of SME to China slid 16% compared to 4Q21; Dutch SME exports to China fell 44% from 4Q21; and U.S. SME exports to China fell 50%.[181] Total semiconductor imports also reportedly fell by 25% in January and February of 2023 compared to the prior year, although the semiconductor industry also fell somewhat.[182] Two of China's most successful and innovative companies have already shown major signs of trouble; GPU and AI champion Biren laid off one-third of its staff

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[176] Matt Sheehan, "Biden's Unprecedented Semiconductor Bet," Carnegie Endowment for International Peace, October 27, 2022.
[177] Elsa B. Kania and Lorand Laskai, "Myths and Realities of China's Military-Civil Fusion Strategy," Center for a New American Security, January 28, 2021.
[178] Ryan Fedasiuk, Jennifer Melot, and Ben Murphy, "Harnessed Lightning: How the Chinese Military Is Adopting Artificial Intelligence," *Center for Security and Emerging Technology*, October 2021.
[179] Joyce Huang, "Observers: China's Chip Talent Hurdle Worsens After Layoffs at US Firm Marvell," Voice of America, November 1, 2022.
[180] Ann Cao, "US Citizens at Chinese Chip Firms Caught in the Middle of Tech War after New Export Restrictions," *South China Morning Post*, October 11, 2022.
[181] Nikkei Staff Writers, "Chip Equipment Exports to China Tumble as U.S. Pushes Decoupling," *Nikkei Asia*, March 29, 2023.
[182] Ibid.

only a week after TSMC halted shipments and announced the resignation of its co-founder,[183] and memory champion YMTC laid off 10% of its workforce[184] while recieving $7B from state investment vehicles.[185] In addition to capital and increased incentives, Chinese authorities were also reportedly considering a since-delayed $145B chip package.[186] Beijing may be souring on direct investments as it navigates the allegations of widespread corruption in the "Big Fund" which have already led to the arrest of general manager Ding Wenwu and other executives.[187]

The potential implications of such bans can be seen from the effects on Huawei and its fabless designer HiSilicon, which were placed on the export blacklist in 2019. In 2018, HiSilicon's Kirin 980 outperformed Qualcomm's Snapdragon 845 in every flagship phone at the time.[188] However, the sanctions prevented HiSilicon from using TSMC, and Huawei's handset offering suffered significantly once their existing Kirin chips were depleted, and had to settle for modified, 4G capped Snapdragons[189] New restrictions will hit Huawei and HiSilicon even harder given SMIC relies heavily on foreign SME. Targeted American sanctions have successfully crippled other Chinese companies, such as state-owned memory firm Fujian Jinhua[190] and, until a deal was struck, telecoms firm ZTE.[191]

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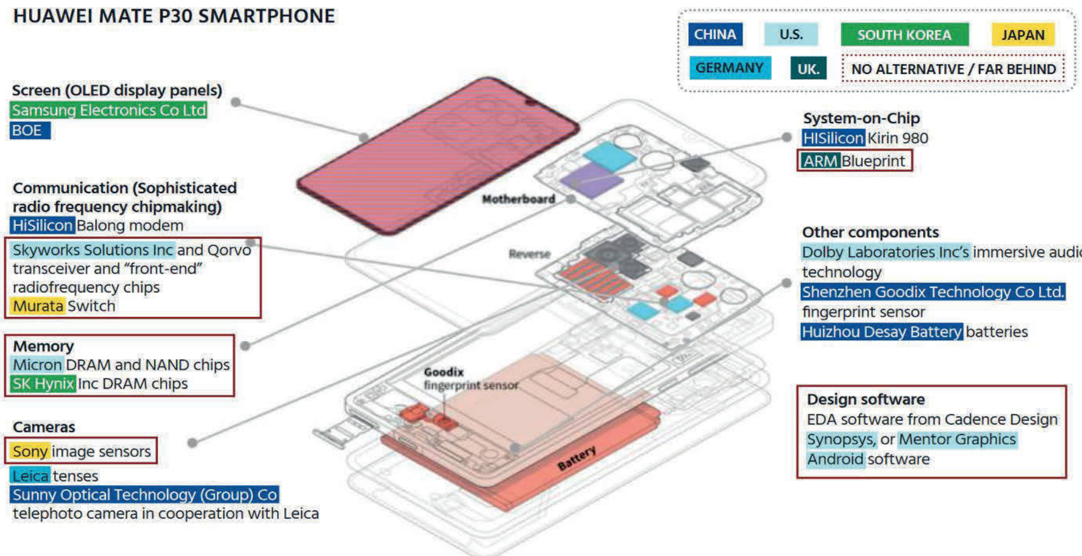
[183] Ann Cao and Pan Che, "Top Chinese Memory Chip Maker YMTC Said to Be Laying off 10 per Cent of Workforce after US Sanctions," *South China Morning Post*, January 30, 2023.
[184] Ibid.
[185] Qianer Liu, "China's YMTC Set for Chip Comeback despite US Export Controls," *Financial Times*, March 30, 2023.
[186] Bloomberg News, "Battered by Covid, China Hits Pause on Giant Chip Spending Aimed at Rivaling US," *Bloomberg*, January 3, 2023.
[187] Zeyi Yang, "Corruption Is Sending Shock Waves through China's Chipmaking Industry," *MIT Technology Review*, August 5, 2022.
[188] Leo Wong, "Huawei's HiSilicon Chips Are Coming Back in 2022, and Rumours Are Already Pouring out in China," Gizmo China, January 11, 2022.
[189] Alan Friedman, "Huawei Denies Rumor That It Will Bring Back Its Kirin SOC for the P60 Series in 2023," Phone Arena (PhoneArena, November 13, 2022).
[190] Kathrin Hille, "Trade War Forces Chinese Chipmaker Fujian Jinhua to Halt Output," *Financial Times*, January 28, 2019.
[191] Ana Swanson and Kenneth P. Vogel, "Faced with Crippling Sanctions, ZTE Loaded Up on Lobbyists," *The New York Times*, August 1, 2018.

Figure 11 shows a teardown of the components in Huawei's P30 smartphone.[192] Recent U.S. restrictions further limiting SME–especially if U.K.-based ARM becomes banned from supplying Chinese companies–would also set back existing Chinese components significantly.



F. Possible responses to export controls

As of April 2023, the Chinese response to the export controls has been limited, perhaps because Beijing does not want to risk more comprehensive sanctions while it is still attempting to build up its domestic ecosystem. China has responded with three notable actions. First, it has slowed and may close reviews for many semiconductor mergers, most notably for Intel's $5.2B acquisition of Israel-based Tower Semiconductors; the size of the Chinese market, as well as U.S. encouragement in prior decades to set up a robust antitrust regime, have resulted in review power that is now a political weapon.[193] This acquisition is critical for Intel—and American chip manufacturing ambitions—given Tower's existing foundries, skilled engineers, and experience

[192] Capri, 45.
[193] Lingling Wei and Asa Fitch, "China's New Tech Weapon: Dragging Its Feet on Global Merger Approvals," *The Wall Street Journal*, April 4, 2023.

in contract manufacturing.[194] Second, it has threatened an export ban for rare-earth materials used heavily in magnets and semiconductors; however, while most of worldwide production is in China, there are sufficient suppliers for most such materials outside China that the West could mine at a higher cost, if needed.[195] Third, Chinese regulators have opened a probe of the American memory producer Micron, which could be used to bar the firm from Chinese markets to make way for YMTC.[196]

Notably, around 2017, Taiwan's UMC and China's Fujian Jinhua (普华集成电路) worked together to recruit Micron employees in Taiwan, who illegally transferred over 900 sensitive files; Jinhua and UMC reportedly even accidently used Micron internal code names in a U.S. event meant to recruit Micron employees.[197] Micron also rejected a $23B 2015 acquisition offer from Tsinghua Unigroup and filed a patent lawsuit against Chinese DRAM maker CXMT in 2018.[198] The White House has reportedly asked Seoul to refrain from filling the gaps in the China market if Micron is banned.[199] These unfolding responses generate additional uncertainty.

G. Potent threat of dumping

The dynamism and competitiveness of the chip industry, along with the need to financially justify large investments to avoid bankruptcy, creates the potential for very effective "dumping," or flooding markets with artificially inexpensive chips to drive competitors out of business. Dumping is especially attractive in the commoditized and volatile memory industry;

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[194] Ibid.
[195] Shunsuke Tabeta, "China Weighs Export Ban for Rare-Earth Magnet Tech," *Nikkei Asia*, April 6, 2023.
[196] Jeff Pao, "Micron Probe by China Seen as Chip War Retaliation," *Asia Times*, April 4, 2023.
[197] Paul Mozur, "Inside a Heist of Micron Chip Designs, as China Bids for Tech Power," *The Seattle Times*, June 24, 2018.
[198] Ibid.
[199] Demetri Sevastopulo, "US Urges South Korea Not to Fill China Shortfalls If Beijing Bans Micron Chips," *Financial Times*, May 24, 2023.

even naturally lower-cost products routinely drive large incumbents out, as previously described. As described in greater detail in **Appendix 1**, YMTC was first to market with a 200+ layer 3D NAND flash solution and was producing 5% of global NAND flash memory chips before the export bans, and even was briefly slated to be part of Apple's M2 memory chip before the company backtracked.[200] YMTC's rapid rise meant the timing of the export ban was very convenient for Micron, Samsung, and SK Hynix. As YMTC has heavy subsidization from the Chinese government (it does not make a profit and relies heavily on government funding), it could survive a grueling price war with market-based firms such as Micron.[201] The threat of dumping remains, especially as China continues to build out their lagging-edge capacity.

H. Uncertain future of Chinese domestic chipmaking capabilities

China's future chipmaking capabilities are therefore highly uncertain. The U.S.'s aggressive export controls and its significant expenditure of political capital with allies suggest the Biden administration expects the Chinese semiconductor industry to struggle more without any access to advanced technology and expertise than it will benefit from the opportunity to tap a massive domestic market previously served mostly by foreign companies.[202] While Chinese chipmaking and access to cutting edge technologies will certainly suffer in the near term, whether China's flagship companies and startups, backed by generous government funding and years of partnerships with foreign companies, are able to capitalize on this newfound customer demand may ultimately shape much of the 21st century.

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[200] Alexandra Alper and Karen Freifeld, "U.S. Considers Crackdown on Memory Chip Makers in China," *Reuters*, August 1, 2022.
[201] Qianer Liu, Eleanor Olcott, and Demetri Sevastopulo, "China's Chip Darling YMTC Thrust into Spotlight by US Export Controls," *Financial Times*, October 14, 2022.
[202] Sujai Shivakumar and Charles Wessner, "Semiconductors and National Defense: What Are the Stakes?," Center for Strategic and International Studies, June 8, 2022.

I. Unclear incentives to reveal semiconductor capabilities

The Chinese government and various Chinese players have competing incentives to advertise their semiconductor progress. Individual firms may advertise their breakthroughs to win further subsidies and investment, and to gain customers, but will want to avoid publicizing their success to the extent it brings stricter U.S. controls. The Chinese government also has mixed incentives, including the desire to justify hundreds of billions of dollars spent and projecting power while also avoiding further export controls. The Chinese government has, for example, touted the remarkable success of firms such as YMTC and HiSilicon, the latter of which recently claimed it can develop software tools (EDA) capable of designing chips down to 14nm.[203] Notably, HiSilicon is unable to manufacture their chips using SMIC, as SMIC relies on older foreign equipment that is only banned from producing chips sold to Entity List companies such as Huawei.[204] In contrast to the broadcasting of this potential HiSilicon EDA achievement, SMIC's unexpected and remarkable breakthrough creating commercially-viable 7nm processes without using EUV lithography (but depending on older foreign equipment) occurred no later than April 2021, but only came to widespread Western attention when analysis firm TechInsights pulled apart a 7nm Bitcoin mining chip built by SMIC in July of 2022.[205]

It should be noted that this SMIC node, labeled as "N+1," is really an advanced 14nm node roughly equivalent to a much lower-end "7nm" node which SMIC was never able to produce at any meaningful scale.[206] Key determinants of success and profitability in a node are utilization rate and output and yield; SMIC succeeded in manufacturing 7nm-equivalent chips

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203 Debby Wu and Yuan Gao, "Huawei Touts Progress Replacing Chip Design Software Led by US," *Bloomberg*, March 27, 2023.
204 Ibid.
205 Scott Foster, "SMIC's 7-Nm Chip Process a Wake-up Call for US," *Asia Times*, July 25, 2022.
206 Rupert Goodwins, "China's 7nm Chip Surprise Reveals More than Beijing Might Like," *The Register*, August 1, 2022.

(which may be all that is needed for the military), but had not succeeded in making it commercially viable, especially without massive subsidies. Node names like "28nm" used to measure a half-pitch, or the distance between two identical characteristics on a chip; since the early 2010s, labels like 7nm and 5nm now mean nothing except the improvement from prior generations.[207] While the efficiency improvements are very real, the names today are little more than marketing.

Characteristic 4: Challenge of Producing Military Power in a Conflict

As described above, any breakdown of supply chains would be disastrous for the semiconductor industry and therefore for supplying militaries. A breakdown would also have critical second- and third-order effects. Semiconductor companies rely on massive consumer demand and global end markets to justify tens of billions of dollars in capital expenditures and R&D. Heightened conflict and the breakdown of supply chains can severely damage both. Even a higher perceived likelihood of an industry-crippling blockade or invasion of Taiwan might shrink reinvestment budgets when the payoff for investments such as $20B+ fabs and intense R&D for designs comes years if not decades into the future.

A. Severe effects of potential conflict on globalized supply chains

A breakdown of global supply chains, even if no facilities were destroyed, would be devastating for semiconductor production. America would instantly lose the majority of its yearly supply of computing power in a blockade, with even more dire consequences if it were also unable to trade with other Asian nations. Even in peacetime, it would potentially take

[207] Semiconductor Engineering: Deep Insights for the Tech Industry, "Nodes," December 4, 2022, https://semiengineering.com/knowledge_centers/manufacturing/process/nodes/.

decades for other nations to replicate Taiwan's current manufacturing output, assembly and test capabilities, and various packaging substrate productions in terms of technological capabilities, much less scale. TSMC alone held ~$88B of Property, Plant, and Equipment at the end of 2022, and has an enterprise value above $400B in April 2023; the cost to rebuild TSMC and its elite professional expertise, while coming close to maintaining its cadence of innovation, would be immeasurably higher, if even possible.[208] The entire industry has come to adhere to the standards set by TSMC and its "Grand Alliance" of customers and suppliers who coordinate standards and communicate design needs, and a lack of coordination would cause further damage.[209]

A blockade of Taiwan alone would heavily cripple international and American chip capacity; even a locally-contained war would destroy it. Taiwanese semiconductor manufacturing is heavily concentrated in key science parks and other clusters on the west coast of the island, easy targets for Chinese hypersonic missiles launched from its southeastern coast.[210] ~60% of all logic chip production and ~90%+ of all cutting-edge logic chips could be destroyed in minutes, possibly seconds. The U.S. National Security Council reportedly estimates the loss of Taiwanese chipmakers could disrupt the world economy by more than $1T.[211] The isolation or destruction of Taiwanese manufacturing would cause unforeseeable rippling effects, and would destroy large parts of the semiconductor ecosystem outside of Taiwan both operationally and financially.

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[208] Company filings, publicly available market data.
[209] Miller, 219.
[210] Clement Charpentreau, "Aerotime Hub," China launches DF-17 hypersonic missile off Taiwan Strait, August 1, 2022.
[211] Jenny Leonard, Debby Wu, and Katrina Manson, "Taiwan Tensions Spark New Round of US War-Gaming on Risk to TSMC," *Bloomberg*, October 7, 2022.

If China does not destroy Taiwan's semiconductor industry, hoping to secure TSMC for itself, Taiwan or America might. The U.S. Army War College's most downloaded paper in 2021 controversially[212] suggests Taiwan should credibly threaten to destroy its semiconductor industry as a deterrent to China, which relies heavily on the island's output.[213] The U.S. may also have a contingency plan in place to destroy TSMC's foundries if the island were to fall, as former National Security Advisor O'Brien may have implied.[214] However, Taiwan's National Security Bureau director-general correctly noted that "TSMC needs to integrate global elements…without components or equipment like ASML's lithography…there is no way TSMC can continue its production…[e]ven if China got a hold of the golden hen, it won't be able to lay golden eggs."[215] TSMC and the Taiwanese semiconductor industry would not function if the island was blockaded, much less invaded, and the implications for the global economy and for militaries would be immense and complex.

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[212] Eric Chan, Peter Harris, and Jared M. McKinney, "On 'Broken Nest: Deterring China from Invading Taiwan'/The Authors Reply Journal Article On 'Broken Nest: Deterring China from Invading Taiwan'/The Authors Reply," *Parameters, U.S. Army War College* 52, no. 1 (April 1, 2022): pp. 167-180.

[213] Jared M. McKinney and Peter Harris, "Broken Nest: Deterring China from Invading Taiwan," *The US Army War College Quarterly: Parameters* 51, no. 4 (November 17, 2021): pp. 23-36.

[214] Chan, Eric, Peter Harris, and Jared M. McKinney. "On 'Broken Nest: Deterring China from Invading Taiwan'/The Authors Reply Journal Article On 'Broken Nest: Deterring China from Invading Taiwan'/The Authors Reply." *U.S. Army War College Quarterly: Parameters* 52, no. 1 (April 1, 2022): 167–80.

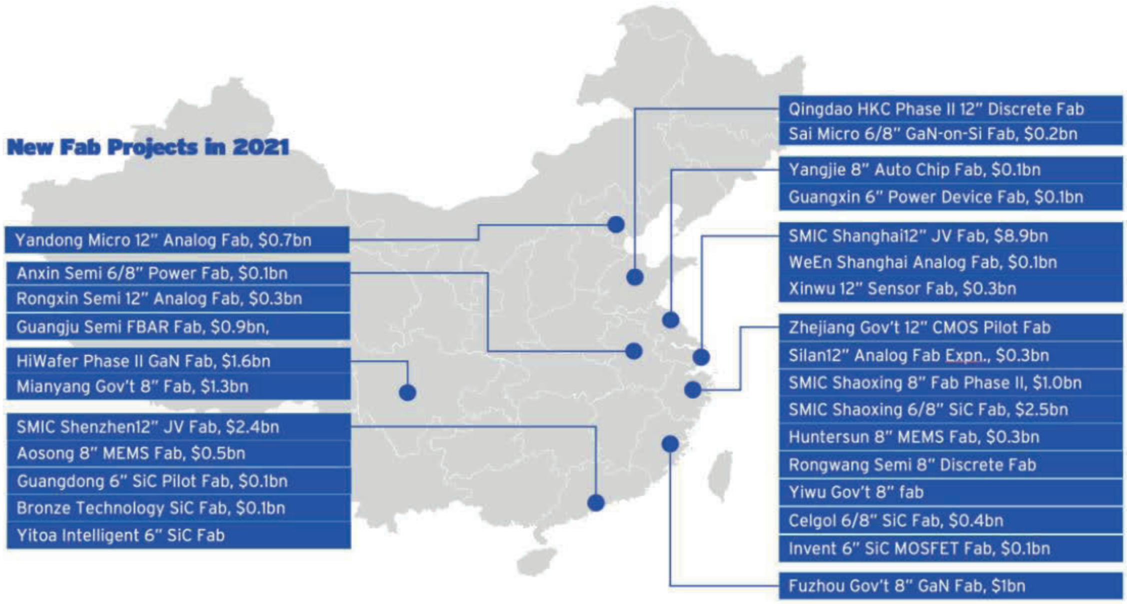
[215] Sarah Zheng and Cindy Wang, "No Need to Blow Up TSMC in China War, Taiwan Security Chief Says," *Bloomberg*, October 12, 2022.

Figure 12 displays a map of Taiwan's foundries, clustered on their Western coast ~110 miles from mainland China.[216]

China's own semiconductor facilities are also clearly identifiable on China's eastern coast, and these massive, delicate facilities could likely easily be rendered inoperable, further complicating China's military planning and war preparedness.

[216] Kathrin Hille and Demetri Sevastopulo, "TSMC: the Taiwanese Chipmaker Caught up in the Tech Cold War," *Financial Times*, October 23, 2022.

Figure 13 shows China's new foundry projects in 2021, clustered on the technologically-advanced eastern and northeastern coasts. Older foundries are also concentrated in the region. [217]



B. Uncertainty surrounding Chinese stockpiles and future access

Chinese companies have been stockpiling chips and equipment for years, especially since the effective sanctions on Huawei, and the military has certainly done the same.[218] Chinese firms have also enjoyed a large window between the announcement of sanctions and their enforcement, allowing them to stockpile all but the most cutting-edge chips and equipment.[219] For American and even Chinese policymakers, it is very difficult to assess how long these stockpiles will last, the scale of Chinese ability to circumvent sanctions, the extent to which their chip stockpiles will become outdated, and the impact of being outdated relative to U.S. systems. Critical Chinese infrastructure and even the Chinese military relies heavily on American chips,

[217] Semiconductor Industry Association (SIA), " China's Share of Global Chip Sales Now Surpasses Taiwan's, Closing in on Europe's and Japan's," January 10, 2022.
[218] Matthew Humphries, "Chinese Firms Are Filling Warehouses With Chip Components, Equipment," PC Magazine (PCMag, February 27, 2023).
[219] Stephen Nellis, "Chipmaking Tool Firms Expect Boom in China Sales despite Export Rules," *Reuters*, April 20, 2023.

and the extent of replacement stockpiles is very important, as demonstrated by the aforementioned fact that 95% of mainland Chinese domestic servers running AI workloads were running on Nvidia chips in 2020.[220] Additionally, a Georgetown review of 343 public AI-related 2020 PLA procurement contracts found that less than 20% of the contracts involved companies subject to export controls, with 22 of the 273 AI equipment suppliers restricted; the PLA has little difficulty buying COTS chips from Taiwan and plugging them into military systems, just as the U.S. has done.[221] PLA suppliers were even discovered advertising access to American chips on their websites.[222] This technology is yielding clear dividends for China; in 2023, the PLA developed a low-cost fiber-optic gyroscope (technology only shared by the U.S.) using DUV lithography which enables the low-cost production of powerful low-end missiles.[223] As further evidence of the importance of both cutting-edge and mature chips, advanced Chinese missiles may use 5nm technology, while these use a 248nm fabrication process.[224] It is very difficult to assess the impact of China's military and commercial stockpiles and their significance

VI. Potential Counterarguments

Counterargument 1: Imitation is Inevitable

One might object to the thesis that semiconductors render anticipation of shifts in the balance of power very difficult by suggesting that China is likely to successfully "imitate"

[220] China Academy of Information and Communications Technology (CAICT), "White Paper on China's Computing Power Development Index."
[221] Fedasiuk et al.
[222] Miller, 286..
[223] Stephen Chen, "Beijing Can Make More Missiles for Less with Breakthrough for Chip-Based Gyroscopes: Paper," *South China Morning Post*, March 1, 2023.
[224] Ibid.

American semiconductor progress, and therefore the balance of power will shift toward China in semiconductors. There are several problems with this counterargument, including that cutting-edge chip production is constantly evolving and increasing in complexity. Many imitated innovations such as nuclear weapons are in many ways a have-it-or-not invention; once a nation has the bomb, they do not lose it. Furthermore, manufacturers such as TSMC do not start on a level playing field for each new generation; they benefit from decades of investment, technical experience, earned trust, and the ability to set industry standards through coordination with customers and suppliers. If this problem could be solved with time and money alone, China would have solved it by 2023, after decades of attempts and well over $100B in direct and indirect subsidies plus far more from private investors.[225] See **Appendix 3** for a brief history of China's decades-long efforts to boost the semiconductor industry, beginning with its labeling as a "key priority" as early as the 1960s, as well as an overview of current direct and indirect subsidies.[226]

The Soviets had decades to replicate American semiconductor dominance and failed, despite early recognition of its significance. A declassified 1959 CIA report found that the U.S.S.R. was consistently 2-4 years behind the U.S. in semiconductor device production, and estimated the value of all types of semiconductor devices was $228.7M for the U.S. and $26.7M for the U.S.S.R., or a ~8.6x greater production value (and an even lower ratio of units).[227] For reference, in 2017, the U.S. had 48% market share, while China had 5%, or ~9.6x.[228] The Soviets

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[225] Na lIand, Shasha Lai, "国家大基金二期落地 两千亿投向何方" [The National IC Fund Phase II landed, where the 200-billion-yuan fund is going to invest]. 第一财经 [Yicai], October 28, 2019;
John VerWey, "Chinese Semiconductor Industrial Policy: Past and Present," United States International Trade Commission Journal of International Commerce and Economics, July 2019, 13.
[226] VerWey,"Chinese Semiconductor Industrial Policy: Past and Present," 10
[227] Central Intelligence Agency, "Production of Semiconductor Devices in the USSR," 1959, 1, https://www.cia.gov/readingroom/docs/CIA-RDP79R01141A001500150002-6.pdf
[228] Semiconductor Industry Association, "2017 Factbook," May 2017.

proceeded to place and turn students and researchers in top U.S. firms and institutes while erecting new Soviet cities dedicated to chip production.[229] By 1985, the CIA assessed that the Soviet Union had acquired every facet of the semiconductor manufacturing processes.[230] A separate declassified Directorate of Intelligence report that same year confirmed that the Soviets could manufacture replicas of some five-year-old chips, but their output was a fraction of the real companies', and the cost per chip was magnitudes higher.[231] The U.S.S.R. failed at semiconductor imitation, chips now are far more complex and international, and innovation is even more driven by reinvesting due to commercial demand; successful imitation is far from assured. What matters is the uncertain question about how much innovation is "enough" from a military perspective.

Counterargument 2: The Russo-Ukrainian War Demonstrates Chips are Not Critical

One might claim that chips have been proven non-essential for militaries, as semiconductor sanctions against Russia and Belarus were swiftly announced in February 2022, and yet Russia has been able to wage war for a year and can still bombard Ukrainian forces. Russia has no meaningful domestic production of semiconductors, and consumed only ~$500M of chips a year before the invasion.[232]

The Russo-Ukrainian War actually demonstrates the extreme importance of semiconductors. Russia's ability to launch precision-guided missiles and accurately hit key targets greatly suffered from their lack of access to high-tech chips, especially in mid-2022,

[229] Miller, 36 and 39.
[230] Central Intelligence Agency, "Soviet Acquisition of Western Technology ," 1982, https://www.cia.gov/readingroom/docs/CIA-RDP83M00914R001200050005-3.pdf
[231] Office of Scientific and Weapons Research, "Soviet Computer Technology: Little Prospect for Catching Up," 1985, https://www.cia.gov/readingroom/docs/DOC_0000498114.pdf
[232] Max A. Cherney, AJ Caughey, and Eric Blom, "Data Reveals Where Russia Chip Sanctions Will Sting the Most," *Protocol*, March 3, 2022.

while Kyiv was launching pinpoint strikes on munitions dumps and bridges.[233] Ukrainian intelligence even claims to have gathered Russian "shopping lists" for various chips, seen and transcribed by POLITICO, which are divided by priority and assigned an estimated cost of sourcing.[234]

Russia's procurement machine has increasingly found ways to bypass sanctions, since ramping up illicit acquisition of Western-designed and Chinese semiconductors of various ages. An analysis by Nikkei of Russian customs data found 2,358 transactions labeled as products of U.S. chipmakers, with a total value of at least $740M. 75% of those transactions and $570M of value came from Hong Kong or mainland China.[235] This process is enabled in part because semiconductor firms typically sell chips through distributors across different channels, who in turn may offload excess inventory to smaller distributors; this contributes to making end-user verification (especially for these dual-use chips) very difficult across hundreds of billions of dollars in sales.[236] In total, Russia imported ~$2.5B of semiconductors during the first nine months of 2022, compared to only $1.8B a year earlier, despite the collapse of non-military demand for chips.[237]

These imported semiconductors have repeatedly been found in abandoned and captured Russian defense systems. One comprehensive tear-down of nearly 30 weapons systems, platforms, and pieces of equipment used by Russia found the majority of components originated

[233] Zoya Sheftalovich and Laurens Cerulus, "The Chips Are Down: Putin Scrambles for High-Tech Parts as His Arsenal Goes up in Smoke," *Politico*, September 5, 2022.
[234] Ibid.
[235] Nikkei Staff Writers, "Special Report: How U.S.-Made Chips Are Flowing into Russia," *Nikkei Asia*, April 12, 2023.
[236] Ibid.
[237] Amanda Lee, "Stymied by the West, Russia Is Getting Critical Semiconductors from Mainland China, Hong Kong," *South China Morning Post*, February 3, 2023.

from 56 U.S semiconductor companies contributing 208 unique components.[238] A further 77 unique components originated from Asian companies, as well as 56 from European companies.[239]

The war has shown semiconductors to be highly important for militaries, and has given impetus to the U.S. and its allies to create more robust common controls, which helped facilitate the October 2022 export bans to China.[240] The scale required by the Chinese economy and military, which had net imports of ~$270B in 2021 vs gross imports of $1.8B for Russia.[241] Additionally, many of the chips Russia is using in their missiles are far from cutting-edge, and similar chips would not allow China to compete with American supercomputers.[242] Russia has been highly focused on acquiring the chips it has to support its military, which would likely be far more effective with sufficiently advanced semiconductors to power advanced precision-guided munitions and other modern military systems.[243] The Russo-Ukrainian war has provided clear evidence for the critical role of semiconductors in modern militaries.

VII. Conclusion

The profound importance of semiconductors for modern militaries and economies has rendered it very difficult to anticipate shifts in the balance of power. The semiconductor industry is highly dynamic and unpredictable, the commercial market dominates innovation and

[238] James Byrne et al., "Silicon Lifeline: Western Electronics at the Heart of Russia's War Machine," Royal United Services Institute (RUSI), August 2022.
[239] Ibid.
[240]Alberto Nardelli, "Russian Memo Said War Leaves Moscow Too Reliant on Chinese Tech," *Bloomberg*, April 18, 2023.
[241] Chinese Semiconductor Industry Association, "2021年中国集成电路产业运行情况 ('The Operation of China's Integrated Circuit Industry in 2021').
[242] Byrne et al.
[243] Sheftalovich and Cerulus, "The Chips Are Down: Putin Scrambles for High-Tech Parts as His Arsenal Goes up in Smoke."

production, militaries are unable to identify and reliably secure the types and quantities of vital semiconductors, and even a local conflict environment in the South China Sea would cripple worldwide semiconductor production. Two potential counterarguments are refuted: the history of Soviet and Chinese chipmaking demonstrate that technological imitation is far from inevitable, and the Russo-Ukrainian War demonstrates that semiconductors are more vital than ever for modern militaries.

The findings of this paper have major implications for theorists and policymakers. Some international relations scholarship suggests that this inability to anticipate shifts in the balance of power will lead to dangerous miscalculations and potentially a higher likelihood for war.[244] This author suggests that the profound importance of semiconductors may prove a durable form of (weaponized) interdependence[245] and even a force for peace, considering the United States and China have shared economic and even military interdependence on Taiwan and global semiconductor supply chains. A conflict may prove that both have mutually-assured destruction with respect to semiconductors, especially given the ease of targeting and destroying foundries. While the U.S. is currently better able to access cutting edge chips, it does not have true escalation dominance over China.

American and Chinese policymakers must analyze all of the above and assess their ability to secure each type of chip and the effects on their power relative to the other in the future. One might image the line of thinking as follows:

1) What will the distribution of capabilities be in the future? Will cutting-edge chips be manufactured by TSMC/Samsung in Taiwan/Korea, by Intel in America, or even by SMIC or another player in China?

[244] Robert Gilpin, *War and Change in World Politics* (New York: Cambridge University Press, 1981)
[245] Henry Farrell and Abraham L. Newman, "Weaponized Interdependence: How Global Economic Networks Shape State Coercion," *International Security* 44, no. 1 (2019): pp. 42-79.

2) Will anyone be able to manufacture sufficient mature chips with supply chains broken down?
3) If manufacturing facilities are working, would each country destroy the other's facilities, which are easily located and highly fragile?
4) What military systems will cutting-edge chips be used for, especially with the divergence of military and civilian needs?
5) Would a potential conflict be most intensely fought by hypersonic missiles and missile defense systems, by battleships and carrier groups, or by supercomputers and cyber warfare? How does each country prepare for a conflict in five years versus a conflict in fifteen, how would the chip requirements differ, and for which should planners most prepare?
6) Can one reliably predict the second- and third-order effects of a breakdown of the semiconductor supply chain?
7) Considering the uncertainty around which chips will matter most and the dynamism of the industry and semiconductor innovation, will the probability-weighted balance of power in the future favor the U.S. or China, relative to today?
8) Given that calculation, what should each country do today? Does either country believe they will have a "window of opportunity" during which they should take decisive action?

A critical development to analyze is the ultimate extent of the export bans and their enforcement. As previously described, China is the world's largest market for semiconductors, serves much of the market for basic packaging, and represents a very large portion of sales for top semiconductor firms. Western firms are attempting to limit the damage to their sales and profits from the export bans, which would also limit reinvestment and innovation. Intel CEO Patrick Gelsinger visited Chinese Minister of Commerce Wang Wentao in April 2023 and the firm subsequently announced it would release modified chips that are not subject to sanctions, such as GPUs with reduced Input/Output bandwidth.[246] Nvidia has also announced a modified GPU "H800" for Chinese markets.[247] SME makers such as Lam and ASML have both announced export sales to China will boom in the second half of 2023, with Lam noting it

[246] Shuliang Li, "搶市場 英特爾推陸規晶片 (To Grab Market, Intel Pushes Chinese-Standard Chips," 工商时报 *"Business Times"*, April 13, 2023.
[247] Stephen Nellis and Jane Lee, "Nvidia Tweaks Flagship H100 Chip for Export to China as H800," *Reuters*, March 21, 2023.

received a “clarification” of the rules that would allow them to sell “a few hundred million dollars” more worth of tools than initially believed.[248] The key question becomes whether these sales are in spite of the intentions of Washington, or at its behest. While many have called for more comprehensive sanctions for lagging edge equipment and near-cutting-edge chips,[249] this paper suggests the above sales are the ideal outcome for Washington. China’s indigenous innovation drives are far more likely to succeed at the lagging edge and then progress to parity or near-parity with the cutting-edge if they can serve the large domestic market. With these limited restrictions, America can at least attempt to control certain specifications such as Input/Output bandwidth, and, critically, maintain substantial leverage over China. While a more comprehensive ban would destroy Chinese chipmaking for a few years or longer, it might very well forge a far more resilient indigenous Chinese ecosystem. A limited ban on the cutting-edge also ameliorates another critical concern, that a comprehensive ban would threaten the Chinese economy and military to the extent that it would almost force the hand of the CCP to take decisive action and escalate the situation, perhaps beginning with an ultimatum that TSMC grant Chinese designers at least equal access to its foundries. While extremely costly for Beijing, such an escalation is a real possibility in the event of a full semiconductor export ban given the potential for large, cascading damage to the Chinese economy and military.

[248] Nellis, “Chipmaking Tool Firms Expect Boom in China Sales despite Export Rules.”
[249] Ben Noon, “Biden Needs to Broaden Semiconductor Sanctions on China,” *Foreign Policy*, April 3, 2023.

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Appendix

Appendix 1: The Semiconductor Industry

Portions of the following are included in the body of the paper.

There are five overarching categories of chips: logic; memory; analog; optoelectronic, discrete, and sensor components; and microprocessors (MPU), microcontrollers (MCUs), and digital signal processors (DSPs).

Logic chips (2021 $155B/~28% of global chip sales), the central block of chips processing data in order to complete a task, are mostly split into several categories: CPUs for PCs (dominated by Intel, AMD); CPUs for mobile (more diversified, led by Qualcomm [especially strong in mobile processors and modems] and Broadcom [Radio-Frequency front-end, Wifi/Bluetooth, GPS] but also systems companies such as Apple); GPUs (dominated by Nvidia, AMD); programmable Field-Programmable Gate Arrays (FPGAs) (AMD via Xilinx acquisition, Intel via Altera acquisition, lesser players Microchip and Lattice); general purpose logic such as simple gates, switches, and registers (highly fragmented, including Xilinx and Altera); and more niche chips and customized integrated circuitry (IC) with increasingly important applications, such as Nvidia's DPU (data processing unit).[250] The above companies, all American-headquartered, often only design these chips, which are typically manufactured by TSMC. Systems companies such as Apple, Google, Amazon, and Tesla have also recently invested hundreds of millions to design custom chip solutions for their computers, data centers, and autonomous vehicles.[251] Chips which serve the large traditional automotive demand (including for driver assistance systems, airbags, engine control, autonomous vehicles, etc.) are

[250] Bank of America Merrill Lynch Equity Research, "Primer."
[251] Shead, "Tech Giants Are Rushing to Develop Their Own Chips — Here's Why."

largely designed and often manufactured by other players such as Renesas (Japan), Infineon (Germany), STMicro (Switzerland but largely in France and Italy), and NXP (Netherlands, with major fabs in the U.S.).[252] The automotive end market is complex and requires separate parts from PCs/Mobile but are typically manufactured on older nodes. Note that microprocessors, microcontrollers, and digital signal processors are sometimes grouped under the "logic category."

Memory chips (2021 ~$154B/28% of global chip sales), used to store information for computing, are largely split between DRAM memory (dominated by Samsung, SK Hynix, and Micron) and NAND Memory (dominated by Samsung, SK Hynix [including acquisition of Intel's NAND business], Kioxia [formerly Toshiba Memory, now mostly independent], Western Digital, and Micron). Note that there are other types of memory, with SRAM and NOR memory also comprising some of the volatile and non-volatile markets, respectively.

Analog chips (CY21 ~$74B/13% of global chip sales, led by Texas Instruments, Analog Devices, Infineon, Skyworks, STMicro, NXP, etc.), used to convert real-world inputs into signals readable by digital logic and memory chips, are less commoditized and more application-specific than memory chips and are therefore less concentrated in a few players. These companies are typically located in the U.S. and Europe.

Discrete, optoelectronic, and sensors (2021 ~$93B/17% of global chip sales) are non-integrated circuit semiconductors and the fragmented supplier base usually sells mature parts at relatively quite low prices. One exception is the emerging role of extremely temperature-resistant compound semiconductors such as gallium nitride (GaN) and silicon carbide (SiC) in new

[252] Bank of America Merrill Lynch Equity Research, "Primer."

technologies such as 5G, autonomous vehicles, renewable energy, and military systems;[253] China has been investing heavily in these third-generation wide–band semiconductors (currently led by U.S.-based Wolfspeed and Japan's Sumitomo Electric Industries), and views them as an opportunity for technological leapfrogging.[254]

MPUs, MCUs, and DSPs (2021 ~$80B/14% of global chip sales) largely execute instructions, perform system control or embedded commute functions, or process digital signals. Each category contains a myriad of functions and key companies performing various tasks based on the end use. As a general rule, MPUs are largely used for PCs and Intel and then AMD lead the market; MCUs are used in many functions but especially automotive and IC cards, and the market is fragmented, led by players such as Renesas, NXP, STMicro, Microchip, Texas Instruments, and Infineon; and DSPs are especially common for processing some digital voice and video signals, and are led by Texas Instruments, followed by Analog Devices and NXP. The majority of these companies are based in the U.S. and Europe, although firms such as AMD and sometimes Intel outsource manufacturing to Taiwan.

Digital logic chips are largely designed by the United States and memory chips are largely designed and manufactured by South Korea, but China has progressed remarkably quickly in certain areas, producing chips that are at the forefront of innovation including some HiSilicon (海思半导体有限公司) logic chips (before sanctions) and YMTC (长江存储科技有限责任公司) memory chips, at least before their respective sanctions.[255] The manner in which these four categories of chips are manufactured differs significantly.

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[253] Julissa Green, "Detailed Introduction to Three Generations of Semiconductor Materials," Global Supplier of Sputtering Targets and Evaporation Materials | Stanford Advanced Materials, January 17, 2020.
[254] Chen, Sharon, Yuan Gao, and Steven Yang. "China to Plan Sweeping Support for Chip Sector to Counter Trump." Bloomberg, September 3, 2020.
[255] Manners, David. "Hisilicon Closing on Qualcomm." Electronics Weekly, March 13, 2019.

Chips are manufactured either using "pure-play" foundries (TSMC, UMC, Global Foundries, SMIC) or by integrated device manufacturers (IDMs) (Samsung, Texas Instruments, Intel). IDMs often manufacture some of their own chips, outsource the fabrication of others, and also fabricate some others for "fabless" designers. Typically, memory and analog chips are designed and produced by IDMs while logic chips are more likely to be fabricated by pure-play foundries. Taiwan, led by TSMC and then UMC, holds 63% of all foundry capacity for logic chips and manufactures 90% of all cutting-edge logic chips (under 10nm), with only Samsung currently competitive at the most advanced nodes.[256] However, it is important to note that larger chips are standard for certain end markets; notably, the automotive sector typically uses 40nm chips. Cutting-edge foundries continue to grow in complexity and cost: a new 14-16nm fab is estimated to cost $13B; a 10nm, $15B; a 7nm, $18B; a 5nm, $20B; and over ten years a current state-of-the-art fab is estimated to cost $40B across initial capital expenditures and annual operating costs without upgrading it to new production nodes.[257] TSMC's new 2nm fab near Longtan Science Park in Taiwan is rumored to cost $32B, and the first iterations of 2nm from this fab are expected to enter the market in 2026.

Foundries can then either manage assembly, testing, and packaging ("ATP," ~10% of chips value) themselves, as some IDMs like Intel and Samsung do for some chips, or take the more common route of using outsourced assembly and test (OSAT) companies which typically have production facilities in Malaysia, Indonesia, Thailand, and/or Vietnam.[258] While ATP is typically an automated and lower-value business, the emergence of chiplets for commercial

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[256] Sullivan and Deese, 35.
[257] Ezell, 15.
[258] Reinsch, William A, Emily Benson, and Aidan Arasasingham. "Securing Semiconductor Supply Chains: An Affirmative Agenda for International Cooperation." Center for Strategic and International Studies, December 12, 2022, 5.

rather than strictly military use (multiple smaller processing modules rather than a single processor on a piece of silicon) has created a sector known as advanced packaging served by niche players like Qorvo and SkyWater but also Intel, Samsung, TSMC, ASE Group, Amkor, and the Chinese champion JCET.[259] Advanced packaging substrates are largely produced in Japan and Taiwan (Ibiden, Shinko, Nanya) but China's existing advanced printed circuit board manufacturing promises an attractive future for its slightly lagging substrate suppliers Shennan Circuits (深南电路股份有限公司) and Zhuhai Yueya (珠海越亚半导体).[260]

The fabrication of chips relies on a large network of semiconductor manufacturing equipment (SME) suppliers primarily concentrated in the United States, Japan, and the Netherlands, as well as electronic design automation (EDA) tools. Back-end test equipment is used in the ATP process; test equipment is led by Japan and the United States, while packaging equipment market share is led by Japan, China, and the Netherlands (although the U.S. is at the forefront of technological innovation for advanced packaging).[261] Front-end SME, which is more technically advanced and represents more of a choke point for Chinese manufacturing, is used in the actual fabrication process and includes lithography, etching, doping/ion implantation, deposition, and polishing or chemical mechanization planarization. The Dutch ASML is the only company capable of producing EUV lithography machines needed for creating circuit patterns on 5nm or smaller chips, and the Japanese Nikon is the only other company offering lagging edge DUV machines (Canon offers a slightly different, inferior machine).[262] Other front-end SME is supplied by the American Applied Materials, the Japanese Tokyo Electron, the American LAM

[259] Sullivan and Deese, 42-43.
[260] Saif M. Khan, Alexander Mann, and Dahlia Peterson, "The Semiconductor Supply Chain: Assessing National Competitiveness," Center for Security and Emerging Technology, January 2021.
[261] FP Analytics, "Semiconductors and the U.S.-China Innovation Race," Foreign Policy, February 16, 2021.
[262] Cagan Koc and Debby Wu, "ASML Shrugs off China Chip Curbs amid Strong Demand Elsewhere," Bloomberg, November 11, 2022.

Research, and the American KLA Corporation; note that many of these American and Japanese companies have key facilities in Southeast Asia. China can perform all these functions only at a level insignificant for cutting edge chips and lacks meaningful share outside of the lower-tech assembly and packaging equipment and Metal-Organic Chemical Vapor Deposition (MOCVD); Beijing has therefore made such SME a key focus of Phase II of China's state-run "Big Fund" for semiconductor development."[263] China's AMEC (中微半导体设备) has emerged as a major player in complex MOCVD equipment, used in the production of GaN and SiC semiconductors, which have important military uses.[264]

The small but critical EDA sector (~$10B in sales), which produces the software semiconductor companies use to design and manufacture chips, is an American triopoly led by Cadence Design Systems and Synopsys, with Siemens' Mentor Graphics a distant third.[265] The close relationships with foundries and the industry-standard "kits" specific to these vendors, as well as the massive potential cost in the case of failure, make these EDA tools very difficult to disrupt or substitute in a free market. Cadence and Synopsys also provide core intellectual property (IP) building-blocks (memory IP, analog IP) used by designers such as Qualcomm; ARM provides a similar licensing service for IP for microprocessors.[266] Advanced front-end SME, ARM IP, and EDA tools remain key choke points for China.

An additional key sector in semiconductor production comprises materials, chemicals, and gases used in production (~$18B in sales). China controls ~70% of polysilicon production capacity and nearly all of the world's Gallium production and reserves.[267] Facilities that slice the

[263] Sullivan and Deese, 52.
[264] Ibid, 50.
[265] Bank of America Merrill Lynch Equity Research, "Primer."
[266] Company filings.
[267] FP Analytics, "Semiconductors and the U.S.-China Innovation Race."

silicon ingots into wafers are mostly headquartered in Japan, followed by Taiwan, Germany, and South Korea, with very little expertise in either the U.S. or China.[268] Photomasks, through which light is shined during lithography to produce the pattern on a wafer, are often produced in-house by Intel, Samsung, TSMC, and SMIC, but many fabless companies use photomask manufacturers concentrated in Japan, the U.S., and Taiwan; however, as more advanced EUV lithography uses mirrors to reflect light, advanced photomasks are significantly different.[269] Japan largely controls the market for photoresists, which are applied to the wafer to form the pattern; the United States and South Korea hold ~10% of the market while China cannot currently produce advanced photoresists.[270] Finally, the United States, Japan, and France are the leading producers of gases used in semiconductor production, while the United States, Germany, and Japan are leading producers of the relevant wet chemicals, although China has been increasing its domestic capabilities.[271]

Appendix 2: China's Current Strengths and Weaknesses

Despite significant progress in verticals such as fabless chip design and advanced packaging and testing, China remains heavily dependent on America and its allies for key technologies including cutting edge fabrication, manufacturing equipment, and electronic design automation (EDA), as well as, to a slightly lesser extent memory, analog integrated circuitry (IC), logic IC, and microprocessors.[272] Additionally, many of China's breakthroughs were only possible using international equipment and manufacturers that are now partially barred from

[268] Sullivan and Deese, 32 and 46.
[269] Ibid, 47.
[270] Ibid.
[271] Khan et al.
[272] He, 9.

serving Chinese customers under recent export bans. In 2022, China remained by far the largest consumer of semiconductors at $180.4B, despite a 6% decrease in total consumption, compared to a 16% increase in the Americas.[273]

China has made great progress in optical devices and low-power embedded processors, sensors, and discrete devices and is approaching self-sufficiency and leading-edge technology in these areas. After some struggles, China has made very significant steps in 2021 and 2022 in memory chips and SMIC's fabrication ability has progressed far faster than expected. The massive market in China, which has been the largest consumer of semiconductors since 2005, is especially helpful for application-specific chips designed in coordination with China's world-class telecommunications and AI companies.[274] These successful adjacent industries have also helped fuel previously-mentioned advances in the potential "leapfrog" technologies of third-generation chipsets using silicon carbide and gallium nitride.[275] Chinese companies are also at the forefront of less advanced packaging and testing, with JCET (长电科技) and SMEE (上海微电子装备) even approaching the cutting edge in advanced packaging and back-end lithography (distinct from front-end ASML lithography).[276]

China's memory industry has grown rapidly, fueled by more than $40B of state investments in NAND memory and another $10-15B invested in DRAM while attracting major investments such as Samsung's 3D NAND Xi'an fab and SK Hynix's Wuxi DRAM and Dalian 3D NAND fabs (acquired from Intel).[277] Even more remarkable has been YMTC (a subsidiary of

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[273] Semiconductor Industry Association (SIA), "Global Semiconductor Sales Increase 3.3% in 2022 Despite Second-Half Slowdown," February 3, 2023.
[274] Seamus Grimes and Debin Du, "China's Emerging Role in the Global Semiconductor Value Chain," Telecommunications Policy 46, no. 2 (March 21, 2022): 6.
[275] Ibid, 10.
[276] He, 19.
[277] Grimes and Du, 10.

Tsinghua Unigroup), which was founded in 2016 and had mostly been at least a generation behind Samsung, Hynix, and Micron since then; its recent Xtacking 3.0 3D NAND solution was poised to become the first 200+ layer solution on the market before the export bans.[278] Apple had even planned to incorporate YMTC as one of its memory suppliers, signaling the strength of the product, especially given the potential political blowback; Apple ultimately froze plans as the Biden administration levied new sanctions.[279] While the other players have similar solutions nearing production, and YMTC is not close to independently generating the cash flow needed to sustain leading edge R&D costs without heavy government involvement, this breakthrough–especially as pandemic lockdowns have complicated its large Wuhan business–is remarkable.[280] However, YMTC's effective exemption from needing to return above a market cost of capital is a major advantage in the relatively commoditized, scale-driven memory industry; the company can continue to flood the market with low-cost chips without worrying about the notorious boom-and-bust cycles that have plagued Samsung, SK Hynix, and Micron, and in the process lower their competitors' effective returns on R&D.[281]

Breakthroughs in memory, design, and fabrication suggest that in the near future China could design and produce near-leading edge chips at meaningful scale domestically (through a mix of domestic companies and multinationals on Chinese soil) if there were no export bans. However, each of these Chinese breakthroughs have relied on certain parts supplied by non-Chinese companies under new export restrictions that will be extremely difficult to replace. China may suffer especially greatly from a lack of ARM architecture for advanced IP chip

[278] Tech Insights, "YMTC's Xtacking 3.0, First to 200+ Layers: This Chinese Company Is Now the Leader in 3D NAND Flash," November 2022.
[279] Ting-Fang Cheng, "Apple Freezes Plan to Use China's YMTC Chips amid Political Pressure," Nikkei Asia (Nikkei Asia, October 17, 2022).
[280] Ibid.
[281] Alex Capri, "Semiconductors at the Heart of the US-China Tech War," Hinrich Foundation, January 17, 2020, 21.

design, 5nm and below chip manufacturing capabilities which rely on banned ASML EUV lithography machines, and EDA software design.[282] Lithography dependence is especially pronounced as, while inferior EDA tools may be used to produce less powerful chips at lower yields and greater cost, only very complex EUV can produce 5nm chips. China's leading lithography company SMEE (which has found great success in back-end lithography) is still well behind and its struggles are amplified by its ban from key lithography suppliers such as the optics company Carl Zeiss (partly owned by ASML) as well as its reliance on Japanese photoresists.[283] Potentially imminent further restrictions on ASML's lagging-edge DUV lithography machines will further damage Chinese capabilities.[284] Chinese SME companies also struggle outside of lithography, although flagship companies AMEC (中微半导体设备) and Naura (北方华创) have found success in low-end IC fabrication equipment such as etchers. Additionally, despite the advances of YMTC, China also still lacks the ability to produce sufficient memory chips and heavily imports memory and analog/power chips.[285] Chinese flagship enterprise SG Micro (聖邦微電子有限公司) cannot compete at the technological level or scale of American companies such as Texas Instruments or Analog Devices, and Chinese self-sufficiency will likely require a range of companies to specialize in the different niches of analog chips.[286] Given the prominence of the IDM model in memory and analog, Chinese enterprises such as Tianjin Zhonghuan Semiconductor (天津中环半导体股份有限公司), Hangzhou Silan (杭州士兰微电子股份有限公司, analog/power) and Unigroup (紫光国芯微电子股份有限公司), the parent

[282] He, 20.
[283] Ivan Platonov and Zheng Xiwen, "Deep Dive: Smee and China's Attempt to Replace ASML Tools," EqualOcean, June 23, 2021.
[284] Cagan Koc, Eric Martin, and Jenny Leonard, "Netherlands Plans Curbs on China Tech Exports in Deal With US," Bloomberg.com (Bloomberg, December 7, 2022).
[285] He, 20.
[286] Ibid.

company of Unisoc and YMTC and since bought out by Beijing Zhiguangxin Holding [a fund led by Wise Road Capital [智路资本] and Beijing Jianguang Asset Management [北京建广资产管理], both seen as instruments of Chinese semiconductor policy; Foxconn/Hon Hai also invested] due to insolvency, mobile CPUs and analog/power[287]) have embraced the IDM model through acquisition sprees but have found limited technological success (outside of Unisoc's low-end IC design) and especially poor financial results.[288] Despite this continued reliance, China is improving both its output potential and technological capabilities.

Appendix 3: Chinese Semiconductor Policy

A. Early Industrial Policy

Beijing has long recognized the importance of developing China's semiconductor capabilities. In the 1960s, Beijing had already identified semiconductors as a "key priority" and IC research led by the Chinese Academy of Science initially surpassed that of Taiwan and South Korea.[289] However, after decades of foreign innovation and domestic setbacks such as the Cultural Revolution, a shocked President Jiang Zemin toured a far more advanced Samsung in 1995 and declared the need to "develop China's semiconductor industry at all costs."[290] However, early state-sponsored initiatives such as Project 908 (developing the IDM Huajing, operator of Wuxi Factory No. 742, through a JV with U.S.-based Lucent) and Project 909 (developing the DRAM chips of Huahong, through a JV with Japan-based NEC) failed, hindered

[287] Peter Clarke, "Tsinghua Unigroup Buy-out Keeps Chip Firms Alive," Electronics Europe News, July 12, 2022.
[288] He, 20.
[289] VerWey, John. "Chinese Semiconductor Industrial Policy: Past and Present." United States International Trade Commission Journal of International Commerce and Economics, July 2019, 10.
[290] Yan Jia and Xiaodong Song, "浦东30年系列之 11: 神秘的"909工程":为何国家领导人说砸锅卖铁也要搞" [Pudong 30 Years series no. 11: Mysterious Project 909: Why the state leader said would do it at all costs]. 上观新闻 [Shanghai Observer], April 14, 2020.

by a rigid bureaucracy, by their lack of dynamism in the ultra-competitive global semiconductor market, by the recession of 2000, and by the memory crash of 2002.[291] Beijing responded by strengthening the 863 and 973 Programs in the Tenth Five-Year Plan and soon after articulating the "Core, High and Basic" (核高基) Project; these broad efforts toward establishing Chinese independence and innovation in cutting edge technologies were especially directed toward CPU chips.[292] In 2005, The State Council's *National Medium- and Long-Term Science and Technology Development Plan Outline for 2006–20* (MLP) correctly emphasized key areas for development, but their solution centered around creating 16 major projects into which capital would be poured and through which China's chip deficiencies would supposedly disappear.[293]

While these catch-up projects yielded some notable successes including the Sunway CPU used in the Sunway TaihuLight supercomputer, their failures have proven emblematic of the issues that continue to hamper Chinese semiconductors. For instance, in an attempt to separate from the West quickly and as fully as possible, the heavily-sponsored Arca CPU designed its Arca-1 chip and related hardware using Linux, so as to avoid Wintel (Windows + Intel CPU–a new alternative is now AA, or an ARM-based CPU using Android that was used by aforementioned national champion HiSilicon). However, Arca PCs and network computers were fully incompatible with the Windows software products that dominated software, and Chinese customers refused to use computers disconnected from modern infrastructure.[294] Indigenous CPU chips suffered a further, major blow when Hanxin 1, heralded as the first digital signal processor (DSP, a type of microprocessor) chip wholly developed in China, was revealed as simply Freescale Motorola DSP 56800s with logos sanded away and replaced with "汉芯一号

[291] He, 4.
[292] People's Republic of China, "Tenth Five-Year Plan."
[293] VerWey, "No Permits No Fabs," 17.
[294] He, 16

."[295] In these early years, schemes focused heavily on rapid "catch-up" attempts that rewarded short-termism and that were often heavily divorced from the reality of markets and even local demand.

B. Modern Policy

Chinese policies concerning semiconductor independence and development have grown increasingly sophisticated in the past decade and are often poorly understood in the West. Previous policies, despite utilizing JVs and foreign expertise, were largely prescriptive, top-down government mandates for specific projects, failing to encourage market-oriented thinking and proper investment and instead resulting in misguided quick-fixes divorced from market realities. Beijing, however, learned from past mistakes and pivoted to a more market-oriented program of subsidization.

In 2014 and 2015, China released *Guidelines to Promote National Integrated Circuit Industry* (National IC Plan) and the *Outline of the Program for National Integrated Circuit Industry Development* alongside the *Made in China 2025,* and the *Made in China 2025 Technical Area Roadmap*.[296] These guidelines established the National Integrated Circuit Industry Investment Fund (National IC Fund or the "Big Fund"), initially endowed with ~$21B and tasked with deploying $150B through 2030 to develop Chinese chips and achieve the aspirational 70% chip self-sufficiency by 2025 stipulated by *Made in China 2025*.[297] By 2018,

[295] David Barboza, "In a Scientist's Fall, China Feels Robbed of Glory," The New York Times, May 15, 2006.
[296] 与非网编辑 , "丁文武解读大基金二期规划，将布局哪些新兴行业," 与非网, March 19, 2018.
[297] Semiconductor Industry Association, "Taking Stock of China's Semiconductor Industry," Semiconductor Industry Association, July 13, 2021.

the initial ¥138.7B (~$20B) was leveraged into total financing of as much as ¥500B (~$70B).[298] The National IC Fund initiated its "second stage" in late 2019, raising another $29B and expanding its focus beyond the fabrication-focus of the first stage.[299] The Fund, besides injecting equity directly into national champions, supplies outbound FDI to acquire foreign companies and encourages inbound FDI through facilitating greenfield investments and JVs.[300] Governance includes a two-tiered management structure in which the board sets strategy and approves major projects but the fund Sino IC Capital is responsible for investing and managing capital.[301] Despite this relatively market-oriented board, the Big Fund is being investigated for severe corruption. The IC Fund nevertheless represents not only a significant capital commitment but also a far nimbler and market-based strategy to develop Chinese chips.

Chinese semiconductor subsidies reach far beyond the national backers of the 2014 IC Fund, however. In addition to the Ministry of Finance (~37% ownership of the initial round) and China Development Bank Capital (~22%), major shareholders include China National Tobacco Corporation, Beijing E-Town International Investment & Development Co., Ltd., China Mobile, and Unigroup.[302] The Big Fund has also served as a fund of funds, investing in firms such as Oriza Holdings and SummitView Capital and thus outsourcing capital allocation to more market based funds while also helping skirt WTO rules.[303] Additionally, the Fund established Sino IC Leasing, in which it invested ¥2B for a 35.2% stake (recently sold down); national champions

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298 Na and Lai, "国家大基金二期落地 两千亿投向何方" [The National IC Fund Phase II landed, where the 200-billion-yuan fund is going to invest].
299 Sullivan, Jake, and Brian Deese, Building Resilient Supply Chains, revitalizing American manufacturing, and fostering broad-based growth: The White House. 100-Day Reviews (2021), 60.
300 VerWey, 13.
301 Erchi Zhang et al., "Five Things to Know about China's Scandal-Struck Chip Industry 'Big Fund,'" Caixin Global, August 12, 2022.
302 Yuan Fan. "集成电路产业突围 '作战图'" ['Combat map' for IC industry breakthrough]. 中国经济时报 [China Economic Times]. February 28, 2018.
303 Erchi Zhang et al., "Five Things to Know about China's Scandal-Struck Chip Industry 'Big Fund,'" Caixin Global, August 12, 2022.

such as Semiconductor Manufacturing International Corporation (SMIC/中芯国际集成电路制造有限公司, which owns 8.17% of Sino IC Leasing) and Yangtze Memory (YMTC/长江存储科技有限责任公司, under Tsinghua Unigroup/紫光集团) have benefited tremendously from cheap financing and bridge loans. For instance, Sino IC Leasing purchases equipment and leases it to firms such as SMIC, which can later choose to extend the lease or purchase the equipment outright.[304] This arrangement provides below-market financing to struggling national champions and also shelters the publicly-listed SMIC from reporting associated capital expenditures and depreciation.

Significant local competition has also emerged in the semiconductor field as local governments and leaders seek investment and political clout. Beyond the Big Fund, Beijing has encouraged the creation of over 15 local IC funds injecting further capital.[305] By 2017, the American-backed Semiconductor Industry Association estimated that provincial and municipal IC-related funds raised over $80 billion, although some of that capital was invested back into the main Big Fund.[306] In recent years, cities and provinces have announced a flurry of incentives for local semiconductor investment. For instance, in January of 2022, Zhejiang province (technology hub which includes Alibaba Group) announced it would increase spending on technological innovation fields by 40% and aimed to support integrated circuitry and digital security with a massive ¥300B (~$45B) in 2022.[307] Only five days later, Shanghai announced the city would

[304] Ibid.
[305] Jennifer Meng and Jimmy Goodrich, "Global Governments Ramp Up Pace of Chip Investments," Semiconductor Industry Association, June 2, 2021.
[306] Office of the United States Trade Representative, "Findings of the Investigation Into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation Under Section 301 of the Trade Act of 1974," Findings of the Investigation Into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation Under Section 301 of the Trade Act of 1974 (2018), 92-94.
[307] Tracy Qu, "Alibaba's Home Province to Offer Preferential Tax Policies," South China Morning Post, January 24, 2022.

subsidize 30% of all investments (up to ¥100M per investment) in semiconductor materials and equipment, chip software such as EDA, and tape-out for chips with 28nm nodes or smaller.[308] Another four days later, the NDRC announced Shenzhen would develop an international sourcing platform for semiconductors and other electronic components, and the city would also serve as a hub for joint procurement and training, among other functions.[309] These initiatives have helped trigger a wave of investment from international firms such as TSMC,[310] SK Hynix,[311] and Mitsubishi Gas Chemical,[312] as well as from national champions such as SMIC,[313] despite an increasingly hawkish Washington industrial policy.

Chinese support for semiconductors, especially since 2018, has been unparalleled. A 2019 OECD report found that, between 2014 and 2018, state subsidies accounted for ~40% of SMIC's, ~30% of Tsinghua Unigroup's, and ~22% of Hua Hong's revenues.[314] However, the total effect of subsidies has been far greater after considering the generous depreciation schedules, below-market loans, and preferred tax treatments which do not impact the top-line. Since 2018, Beijing and local governments have facilitated the construction of more than 52 fabs through equity investments alongside grants, reduced utility rates, favorable loans, and tax breaks, and in 2020 announced a provision providing up to a 10-year corporate tax exemption for semiconductor manufacturers.[315] National policy has also become increasingly favorable,

[308] Zhao and Pan, "Why Has TSMC's Nanjing Expansion Plan Stirred up a Hornets' Nest in Beijing and Taipei?"
[309] Iris Deng, "China to Build Global Sourcing Platform for Semiconductors in Shenzhen," South China Morning Post, January 26, 2022.
[310] Che Pan, "TSMC Says Nanjing Fab Expansion on Track as Second Quarter Revenue Surges," South China Morning Post, July 15, 2021.
[311] Tracy Qu, "China-Korea Venture Develops New Semiconductor Industrial Estate," South China Morning Post, October 8, 2021.
[312] Yuri Masuda, "Mitsubishi Gas Chemical to Build Chip Cleaning Agent Fab in China," Nikkei Asia (Nikkei Asia, February 12, 2022).
[313] Che Pan, "SMIC's New Shenzhen Semiconductor Plant Offers Glimpse at China's Effort to Fight Global Chip Shortage," South China Morning Post, October 26, 2021.
[314] Organization for Economic Cooperation and Development (OECD), "Measuring distortions in international markets: The semiconductor value chain" (OECD, November 2019), 98.
[315] Meng and Goodrich.

especially after the 14th Five Year Plan elevated technological development to a national security issue;[316] Beijing pledged to increase R&D spending by 7% per year and waived import taxes on raw materials and equipment parts for most domestic producers of logic and memory chips.[317] However, while these state investments are unparalleled, it is important to recognize that incumbents spend heavily on capex and R&D each year, have experience effectively spending and building on prior investments, and are less constrained by political pressure; in FY22 alone, TSMC spent $44B on capex (2020 and earlier capex was typically ~$15B) and another ~$5B on R&D.[318] Despite the heavy subsidization of the semiconductor sector, China still controls a very small part of the global industry, and remains weak at key critical junctures.

[316] Qin, Amy. "China's Plan to Win in a Post-Pandemic World." The New York Times, March 5, 2021.
[317] Pan, Che. "China Semiconductor: Beijing to Waive Taxes on Imported Materials, Parts until 2030 in a Boost to Self-Reliance Drive." South China Morning Post, March 30, 2021.
[318] Company filings.