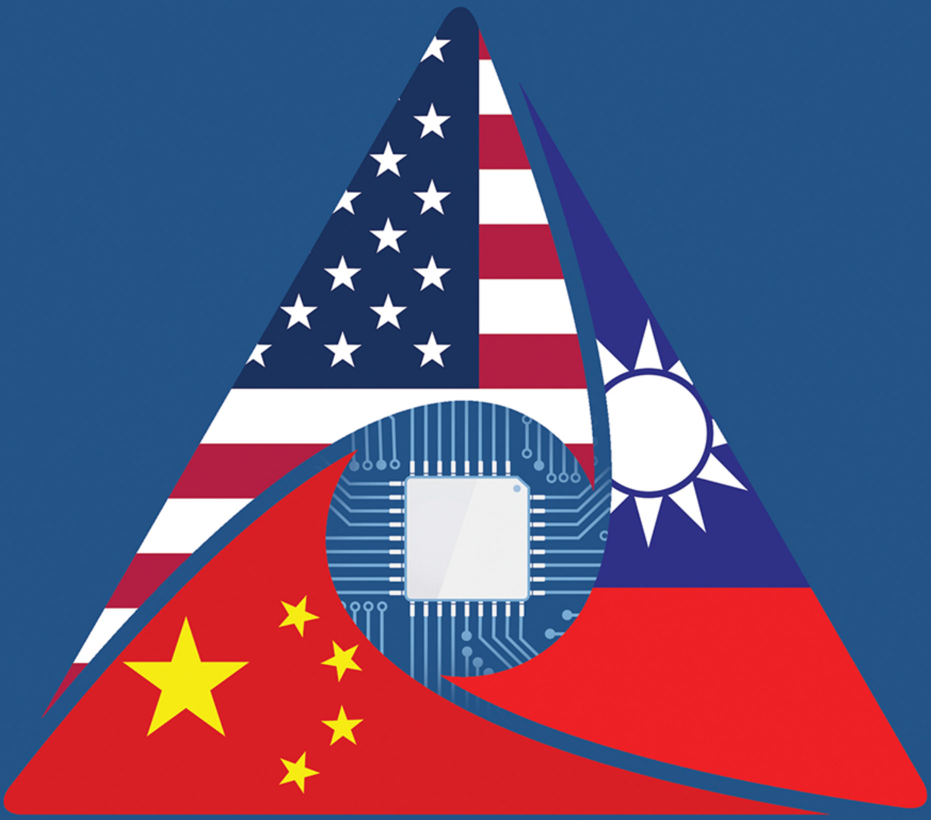

Silicon Triangle

The United States, Taiwan, China, and Global Semiconductor Security

Edited by Larry Diamond, James O. Ellis Jr., and Orville Schell

CHAPTER EIGHT

China's Lagging Techno-Nationalism

GLENN TIFFERT

What tools has China historically employed to improve its semiconductor supply chain competitiveness and self-sufficiency—and what are the prospects for its future success? So far, China has a mixed record on policy design and execution. But, as in other sectors, it can be expected to sustain great losses over time as it continues adjusting its approach.

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In 2021, China's national market for semiconductors was the largest in the world at $192.5 billion in sales or nearly 35 percent of the global total.[1] After decades of generous state support, capital stock in China's semiconductor industry has mushroomed, but the value of production by companies headquartered there is still only about 6.6 percent of consumption, and indigenous firms lag in many key segments of the market.[2] China's dependence on imported semiconductors, and the technologies and inputs to manufacture them, therefore, remains acute.[3] In addition, profitability has been elusive because of inefficiency, corruption, predatory pricing, and the cost of foreign licenses. While China's policy makers have redoubled their efforts to modernize the country's technology base, cultivate self-sufficiency, and improve the security of its supply chains, intensifying US countermeasures cloud their prospects for success and may thwart their plans for years to come.

Industry Origins in Techno-Nationalism

A defiant strain of techno-nationalism animates China's industrial policy on semiconductors.[4] Across the nineteenth and twentieth centuries, technological inferiority left China prone to repeated foreign aggression and invasion. Some in China draw parallels between that "century of humiliation" and the frustrated ambitions that their country purportedly suffers today at the hands of US power. Under General Secretary Xi Jinping, a "never again" mentality has grown more prominent, and those who share it dream of turning the tables on any who would try—for example, through export controls—to contain China, keep it down, or "strangle" (卡脖子) it. For Xi, the stakes are high. He has personally cited China's ostensible capacity to innovate, achieve technological breakthroughs, and recenter the world economy around itself as proof that his signature "new type whole-nation" (新型举国体制) socialism is superior to competing ideological systems.[5]

China's government first incorporated semiconductors into state planning and industrial policy in 1956, and for a short while, China counted itself at the forefront of East Asia in this emerging technology. It created its first integrated circuit in 1965, seven years after the United States. By the 1970s, however, China had fallen far behind some of its neighbors, and it has struggled to catch up ever since.

From 1990 to 2014, China's government undertook a succession of state-led development projects that fell far short of their goals but nonetheless laid the foundations for today's achievements.[6] Step-by-step, it imported machinery, established joint ventures with foreign partners, sent students abroad to study and acquire industry experience, hired expatriate talent, courted foreign capital, and pursued foreign intellectual property (IP) and trade secrets both legally and illicitly—all to facilitate technology transfer and build national champions. China's accession to the World Trade Organization (WTO) in 2001, its enormous and increasingly affluent consumer base, its centrality as a manufacturing hub for the global electronics industry, expanding state incentives, and protectionist local procurement policies all accelerated its progress. Some of today's leading firms—such as Huahong Group (comprising Hua Hong Semiconductor, HH Grace, and Shanghai

Huali) and Semiconductor Manufacturing International Corporation (SMIC)—were among the principal beneficiaries.[7]

But while China's semiconductor industry advanced quickly in these decades, it failed to catch up to its foreign competitors—they moved faster, and each successive generation of technology involved higher barriers to entry. Apart from Huawei's HiSilicon subsidiary, no domestic firms achieved breakthrough success as designers or manufacturers for the commercial market. Similarly, China's trade deficit in semiconductors widened because growing demand outpaced gains in domestic output. Frustrated, China's government responded not by changing course but by intensifying its mercantilist promotion of import substitution and national champions, as well as by its pursuit of foreign technology and know-how.

Doubling Down after 2014

In 2014, the State Council released a Guideline for the Promotion of the Development of the National Integrated Circuit Industry, one of sixteen megaprojects envisioned by an earlier Medium- and Long-Term Plan for Science and Technology (2006–2020; see table 8.1 for a timeline of the Guideline and other key national policies since 2014).[8] Like many industrial policy initiatives launched under Xi Jinping, the Guideline was a bold, campaign-style plan that mobilized resources on a grand scale and framed success as a test of discipline and will. Its goals included mastery of process nodes down to 16–14nm and the development of advanced indigenous players in assembly, packaging and testing, equipment, materials, and design segments. It proposed a national investment fund ("Big Fund") to finance these plans, as well as favorable tax treatment and complementary venture capital, equity investment, and debt-financing tools. To accelerate the transfer of technology and skills, it recommended strengthening cooperation with foreign R&D institutions and "vigorously promoting" recruitment of overseas technical, managerial, and entrepreneurial teams, including via the Thousand Talents program.[9] Fractal measures at the local and provincial levels followed.[10]

Table 8.1. Timeline of Major National-Level Semiconductor Policies in China

YEAR	POLICY	DETAIL
2014	Guideline for the Promotion of the Development of the National Integrated Circuit Industry (the 2014 Guideline), State Council	Marked the start of the current phase of semiconductor policy. Set initial targets, tax relief, direct financing, and equity capital through state-linked central and regional investment funds. Established the National Integrated Circuit Industry Investment Fund I (Big Fund I), raising a total of ~$20 billion. In 2019, Big Fund was recapitalized as Big Fund II with ~$32 billion of registered capital.
2015	Made in China 2025 (MiC 2025), State Council	Focused attention on China's goals for self-sufficiency. Set specific targets for attaining 40% self-sufficiency in China's semiconductor consumption by 2020 and 70% by 2025. Directed that China's enterprises reach the "international first grade" by 2030 in process equipment at nodes of 90nm and below and in lithography equipment, including extreme ultraviolet (EUV).[a] Targets proved unrealistic—has since exited official discourse.
2015	Digital Silk Road (DSR)	Entered official discourse as an extension of the Belt and Road Initiative (BRI). Likely goals: expand end markets for China's technology companies, serve a set of strategic goals, and increase adoption of China's digital standards.
2016	13th Five-Year Plan for Science and Technology Innovation 2016–2020 (13th FYPSTI), State Council	Semiconductor goals included 14nm etching equipment and 28nm immersion lithography machines.
2020	Several Policies to Stimulate a New Era of High-Quality Integrated Circuit and Software Development (Several Policies), State Council	Offered conditional tax breaks to leading-edge manufacturing (<28nm), design, and software companies; improved import tariff exemptions for materials and equipment. Offered an accelerated IPO review process for companies to list on relevant exchanges.

Table 8.1. (*continued*)

YEAR	POLICY	DETAIL
2021	14th Five-Year Plan 2021–2025 (14th FYP), State Council	Treated semiconductors as an independent category (unlike the 13th FYP), one of seven frontier technologies prioritized for national breakthroughs.
		Specifically aims for breakthroughs in integrated circuit design tools, key semiconductor equipment and materials, advanced-memory technology, and third-generation wide-bandgap semiconductors.[b]

[a]John Lee and Jan-Peter Kleinhans, *Mapping China's Semiconductor Ecosystem in Global Context: Strategic Dimensions and Conclusions*, Stiftung Neue Verantwortung and MERICS, June 2021.

[b]Xinhua News Agency, "中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲," March 13, 2021, http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm (CN).

The Made in China 2025 plan and the 14th Five-Year Plan (2021–2025; 14th FYP) reaffirmed this framework. The 14th FYP lists semiconductors among seven frontier fields to "attack" (攻关), calling specifically for research and development in design tools, key equipment, and high-purity materials; breakthroughs in insulated-gate bipolar transistors and microelectromechanical systems; advances in memory technology; and the development of wide-bandgap semiconductors (silicon carbide, gallium nitride, and other varieties).[11] In support of these priorities, national ministries, provinces, and localities again issued a cascade of complementary policies.[12]

State support for China's semiconductor industry is growing. According to one assessment, by 2021 the state controlled or owned 43 percent of the industry's registered capital.[13] The Organisation for Economic Co-operation and Development (OECD) calculated the share of state subsidies in total firm revenues for three of China's largest indigenous semiconductor manufacturers from 2014 to 2018; the results were SMIC, 40 percent; Tsinghua Unigroup, 30 percent; and Hua Hong, 22 percent. The comparable figure for three leading foreign firms—Taiwan Semiconductor Manufacturing Company (TSMC), Samsung, and Intel—was approximately 3 percent.[14] Likewise, a 2019 estimate valued China's total assistance to its semiconductor industry at 137 percent of global sales—compared to 11 percent for Japan, 3.8 percent for Taiwan, 2.3 percent for the European Union (EU), and 0.01 percent for each South Korea and the United States.[15] By one calculation, the ten-year total cost of ownership for a new manufacturing facility ("fab") in the United States is 37 to 50 percent higher than in China, and as much as 40 to 70 percent of that difference is directly attributable to People's Republic of China (PRC) government incentives.[16] These incentives include $73 billion in state-linked semiconductor investment funds at the national and local levels, as well as an unspecified quantity of government grants, reduced utility rates, free or discounted land, and concessional loans, the last of which may exceed $50 billion.[17] But even this accounting likely omits other forms of support. For instance, in 2021 the Shanghai municipal government alone set aside $50 billion in financing for a Shanghai integrated circuit cluster backed by the Ministry of Industry and Information Technology.[18]

These sums and the political signaling behind them sparked a gold rush. Between 2014 and 2020, the quantity of venture capital flowing into China's semiconductor industry grew more than tenfold.[19] Between 2014 and 2021, more than 110 new fabs were announced in China, with a total committed investment of $196 billion.[20] Entire production teams were recruited from Taiwan and Korea to staff these facilities and train local personnel. A 2019 report estimated that more than three thousand engineers—equivalent to nearly 10 percent of Taiwan's R&D workforce in semiconductors at the time—moved to China, lured by salaries double to triple what they could earn at home.[21] The transplants included luminaries such as former TSMC chief operating officer Chiang Shang-yi, former TSMC and Samsung senior executive Liang Mong-song, Inotera Memories chairman Charles Kao, and former United Microelectronics Corporation (UMC) vice chair Sun Shih-wei.

Today's Mixed Results

This combination of state support, technology transfer, and protectionism has yielded mixed results. On the one hand, in 2021 China ranked sixth in global semiconductor sales, according to estimates from the

Semiconductor Industry Association (SIA) and IC Insights, a market research firm. (See figure 8.1: note that "sales" refers to the final purchase of chips, which often goes through a chip designer independent of manufacturing location; for example, a US sale for 2023 would include US fabless chip design firm Qualcomm contracting with TSMC fabs in Taiwan to produce its latest Snapdragon 8 Gen 2 chips in order to be sold to PRC smartphone producer Xiaomi.)

Likewise, China has a 46 percent share of the global market in assembly, packaging, and testing, and it produces around one-quarter of the world's NAND Flash memory (including through Korea-based firms manufacturing in China). Overall, China has approximately one-quarter of the world's installed chip (wafer) manufacturing capacity—nearly all of it in high-volume, trailing-edge products (again, including fabs in China owned by foreign firms).[22] China's share of this segment is expected to grow rapidly as new fabs come online.

China-based firms have built notable positions in some segments of the global chip supply chain (table 8.2). For example, boosted by local procurement policies, China's largest indigenous pure-play foundries—SMIC, Hua Hong Semiconductor, and Nexchip—are ranked fourth, fifth, and ninth by worldwide chip manufacturing revenue in 2021, with 5.1 percent, 2.7 percent, and 1.1 percent global market shares, respectively. By comparison, industry leaders TSMC and Samsung accounted

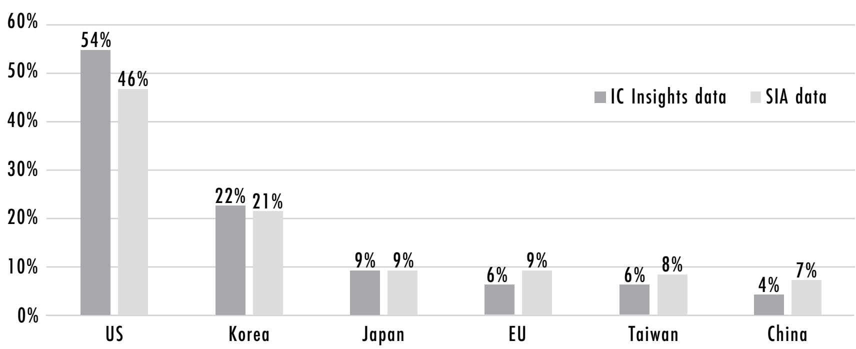

Figure 8.1. Share of Global Semiconductor Sales in 2021, by Corporate Headquarters Location

Source: Research Bulletin, *IC Insights*, April 5, 2022, Semiconductor Industry Association, 2022 Factbook, April 21, 2022, 3.

Table 8.2. Rankings of Leading PRC Semiconductor Manufacturing Firms by Category (2021)

MANUFACTURING SEGMENT	COMPANY	GLOBAL MARKET RANK WITHIN SEGMENT	GLOBAL MARKET SHARE WITHIN SEGMENT
Pure-play foundry[a]	SMIC	4	5.1%
	Hua Hong	5	2.7%
	Nexchip	9	1.1%
DRAM[b]	ChangXin Memory Technologies (CXMT)	5	1.4%
NAND[c]	YMTC	6	4.4%

[a]Thomas Alsop, "Leading Semiconductor Foundries Revenue Share Worldwide from 2019 to 2022, by Quarter," Statista, June 20, 2022.

[b]Horizon Advisory, "Project 506: CXMT and China's Semiconductor Industrial Policy," December 2022; Tom Coughlin, "ChangXin Memory Technologies Supplies Chinese Consumer DRAM Market," *Forbes*, June 9, 2021.

[c]Kim Eun-jin, "US Moving to Limit NAND Production Equipment Exports to China," *BusinessKorea*, August 3, 2022.

for 53.2 percent and 17.5 percent of manufacturing revenue.[23] In 2022, SMIC began mass production at the 14nm node and, as described earlier in this report, surprised the world with a rudimentary 7nm application-specific integrated circuit (ASIC). Also in that year, Yangtze Memory Technology Corporation (YMTC) leapfrogged the competition by releasing the world's first NAND Flash memory chips with more than two hundred layers.[24] YMTC's share of global NAND production grew from 1 percent in 2020 to around 5 percent in 2021, reportedly assisted by $24 billion in subsidies.[25]

GigaDevice, a fabless designer of NOR Flash memory (used in applications such as medical devices that require high reliability), ranked third in the world by sales in 2021, with a 23.2 percent share in that specialized market.[26] Startup NETINT's video processing units (VPUs), while still a small and specialized market, are widely used by content-delivery networks, social media platforms, and data centers in

China.[27] Finally, Quectel, Fibocom, and Sunsea captured half of the global market for the cellular internet-of-things (IoT) modules embedded in smart meters, point-of-sale terminals, health care devices, autos, and industrial systems. Use of PRC vendors in these technologies that interface with the physical environment has drawn concerns about data security and privacy.[28]

On the other hand, critical gaps remain in China's domestic semiconductor supply chain.[29] For instance, China has no major analog mixed-signal microprocessor, microcontroller, or specialty logic manufacturers in the global market, and its industry remains dependent on essential intellectual property from abroad—in particular, the electronic design automation (EDA) software used to design chips and the instruction set architectures (ISA) and IP cores that define them.[30] (As described in chapter 2 of this report, an ISA describes the interface between a device's processor and the software that runs on it. A well-known example is the x86 standard pioneered by Intel. IP cores, such as those offered by the UK-based company ARM, provide discrete blocks of functional logic that designers can license for incorporation into their chips.[31]) Additionally, China's equipment manufacturers trail the market leaders.[32] China is self-sufficient only as far as the 90nm process node because of the limitations of its indigenous semiconductor manufacturing equipment suite—indeed, its most advanced indigenous equipment, in areas of etching and thermal processing, reaches no further than the 28nm node.[33] Recent US export controls target those bottlenecks by blocking access to more-advanced foreign technologies—a move that will pressure China to devise circumvention strategies and alternatives.[34]

Despite hundreds of billions of dollars in state support, output has fallen far short of policy goals. While the value of semiconductor production by foreign and domestic firms in China greatly expanded in absolute terms, as a share of domestic consumption, it rose by less than two percentage points between 2014 and 2021, from 15.1 percent to 17 percent.[35] Foreign firms operating within China outproduced indigenous firms by a factor of two in 2020 and will continue to lead through at least 2025. According to official PRC customs statistics, in

Table 8.3. Made in China 2025 Performance Report

YEAR	TARGET	ACTUAL PRODUCTION	BY INDIGENOUS FIRMS
2020	40%	15.9%	5.9%
2025	70%	19.4%*	7.5%*

(*) = Forecasts

Source: IC Insights, "China Forecast to Fall Far Short of Its 'Made in China 2025' Goals for ICs," January 6, 2021.

2021 the dollar value of China's semiconductor imports was approximately twenty-eight times higher than that of its semiconductor exports.[36] The scale of this imbalance is due to China's dual status as the producer of 36 percent of the world's electronics and the second-largest final consumer market for electronics with semiconductors.[37]

The share of consumption produced by indigenous firms paints an especially unflattering picture. The Made in China 2025 plan boldly set self-sufficiency targets of 40 percent for 2020 and 70 percent for 2025. An industry publication estimates that China achieved just 5.9 percent self-sufficiency in 2020 and forecasts 7.5 percent in 2025 (table 8.3).[38]

What Held China Back?

The limits on China's past performance were attributable mostly to local factors, of which four were central: human capital, economics, fraud, and clientelism.

First, China's semiconductor industry has struggled to source qualified talent at home and has relied heavily on recruitment from abroad for its senior managers, engineers, and developers. Workforce development remains a severe bottleneck. In 2020, China graduated 210,000 college students with semiconductor-related majors, but many of them reportedly had weak skills, and despite high youth unemployment, just 13.77 percent of them entered the semiconductor industry. And trends remain unfavorable. China's labor pool is shrinking, only 12.5 percent of it has graduated from college, and those with technology majors have many career options in China and beyond.

Furthermore, turnover within the industry is high because of a demanding work culture, fierce competition, and the lure of other high-tech professions. Foundries, in particular, struggle to retain talent because the government entities and state-owned enterprises that invest in them are oriented toward output maximization rather than staff development, and high capital costs constrain operating budgets. In 2020, 17 percent of SMIC's employees left the firm, compared to a 12.5 percent turnover rate in the industry at large. Industry watchers report that engineers who staff production lines are leaving for design work, which offers higher pay and shorter, more predictable hours—the relative attractiveness of working in software-oriented rather than manufacturing roles is a phenomenon also observed in the United States, as described in chapter 2. Firms are scrambling to replace them and keep pace with ambitious expansion plans. Analysts predict more than two hundred thousand unfilled positions in China by 2023, though slumping demand for semiconductors may reduce that shortfall.[39]

Second, market forces militated against leadership and self-sufficiency. In general, China's semiconductor policy has pursued a two-track approach: one, cultivating a secure domestic production base of national champions through local procurement policies, state-assisted technology transfer, and preferential access to incentives; and two, fostering a vibrant ecosystem of other firms connected to the global marketplace and compelled to compete in it. The hope was to create a virtuous cycle in which the latter would power domestic innovation and elevate the former. But the contradictions between the mercantilist and market principles underlying each pole in that relationship have proved difficult to bridge.

By insulating a subset of firms from foreign competition and market discipline—as well as taking a firmer hand in their management—the central government has impeded efficiency and innovation where it needs them most. Seeking lower investment risk and higher returns on capital, provincial and local governments commonly passed over indigenous firms in favor of prestigious foreign rivals with superior technology and proven capabilities. Global leaders such as Intel, SK hynix, Samsung, TSMC, and UMC capitalized on this preference, feasting on state incentives to shift manufacturing to China. To this day, these foreign outposts dominate China's output. They have brought sought-after technology, trained local personnel, and stimulated an ecosystem of secondary suppliers—all of which, over time, may yet lift the competitiveness of China's national champions. But until the indigenous firms are more exposed to market discipline, their potential to lead in technology—let alone in volume or price—remains an open question.

Venture capital has also followed the market, further suppressing local self-sufficiency in favor of the distributed division of labor that is typical of other global supply chains. Hence, in 2020, 67.2 percent of venture capital deals in China's semiconductor industry involved design firms, drawn by comparatively low startup costs. This investment catapulted China to third place among the world's fabless design centers. By one estimate, as of 2022 about a dozen firms in China were producing 5nm designs, and some were on the cusp of advancing to 3nm.[40] To realize their creations, these designers used the most-advanced tools and partners available to them—US software and Taiwan's foundries—and irrespective of export controls, the knock-on effects of design firms doing so left China lagging in many key segments, including EDA tools, manufacturing equipment, supporting software architectures, and high-end materials, particularly wafers and chemicals.[41] So long as indigenous firms could tap the best of what the world had to offer, local investors had low economic incentives to reinvent the wheel (see figure 8.2).

Third, the state consequently had to shoulder much of the capital-intensive burden of self-sufficiency by itself—and, as with past "great leaps forward," hyperbole, waste, and corruption flourished. Drawn by official largesse, a tidal wave of firms registered as integrated circuit–related enterprises—fifty-eight thousand during the first ten months of 2020 alone. A great many hastily rebranded themselves from other lines of business, reportedly squandering state assets as "three no" (三无) enterprises: no experience, no talent, and no technology.[42]

Dozens of promised fabs were never delivered, and some of the most high-profile projects and firms collapsed amid lurid scandals and allegations of fraud. The case of Wuhan Hongxin was notorious. In

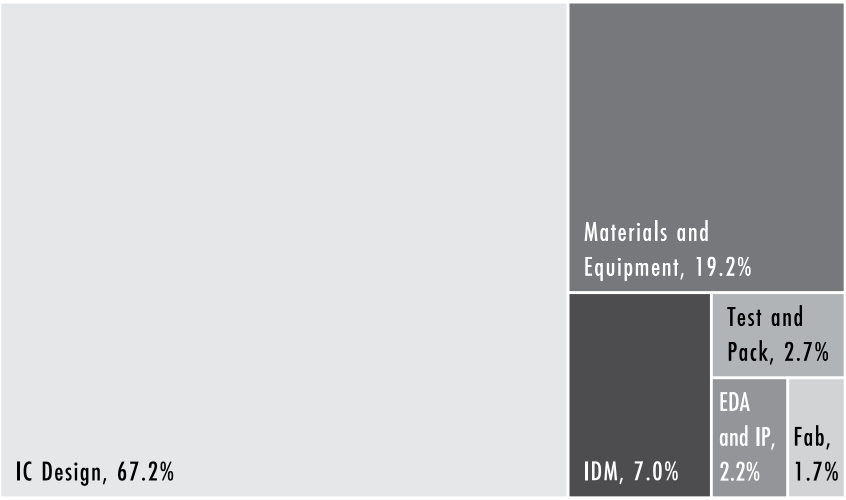

Figure 8.2. China Semiconductor Venture Capital Investment by Sector (2020)
Note: IDM = integrated device manufacturer; IC = integrated circuit
Source: Jane Zhang, "China's Semiconductors: How Wuhan's Challenger to Chinese Chip Champion Turned from Dream to Nightmare," *South China Morning Post,* March 20, 2021. Investment data from Winsoul Capital.

early 2018, officials in the city of Wuhan broke ground on a site that was billed to include China's first 7nm production line as well as a companion 14nm line, each to have an output of thirty thousand wafers per month. The project recruited Chiang Shang-yi, former chief operating officer of TSMC, to serve as chief executive of a team that comprised more than one hundred engineers from TSMC. According to municipal authorities, it would ultimately involve $18.5 billion in investment, of which more than $2 billion had been delivered by the end of 2019. But when the project collapsed the following year, no buildings were complete, and today the site lies derelict. Among its cofounders, one had no more than an elementary school education and was operating under a false identity; another was known as a vendor of traditional herbal medicine and tobacco rather than high-tech goods. Both vanished.[43] Between 2019 and 2021, at least five other major chip ventures also failed, including a $100 million joint venture between US-based GlobalFoundries and the Chengdu city government that was touted as a "miracle"—but never started production. Projects by

Tacoma Semiconductor and Dehuai Semiconductor met similar fates, but after securing billions of renminbi (RMB) in state financing.[44]

No firm soared as high or fell as hard as Tsinghua Unigroup. Led by a real estate mogul with extraordinary access to state credit, the firm entered the semiconductor business just ahead of the opportunities created by the 2014 Guideline and quickly spent its way to the top of China's semiconductor industry. Over a five-year period, it sought to invest $47 billion in Western companies, including a $23 billion bid for Micron that jolted US regulators into heightening their scrutiny of PRC investments and was ultimately blocked by the Committee on Foreign Investment in the United States (CFIUS) process. After defaulting under a $30 billion mountain of debt, Tsinghua Unigroup filed for bankruptcy in 2021 and reemerged after a court-led restructuring and ownership change the following year.[45]

Fourth, beyond straightforward fraud, the marriage of state power and capital behind such deals also reinforced more subtle existing pathologies of governance in China by creating rich opportunities for intra-elite competition, clientelism, and rent seeking. For instance, Jiang Mianheng, son of late Party General Secretary Jiang Zemin, personally presided over Shanghai's emergence as China's semiconductor capital via a network of investment vehicles through which he channeled immense quantities of state and foreign capital.[46] In Beijing, Tsinghua Unigroup's meteoric (if fraudulent) rise actually began when Hu Haifeng, son of Party General Secretary Hu Jintao, served as its corporate party chairman. In a 2020 article since deleted, state media explored shadowy connections between the Wuhan Hongxin debacle and senior military figures, including air force general Liu Yazhou and his younger brother, PLA intelligence department major general Liu Yasu, who were quietly arrested in December 2021. The older Liu is the son-in-law of the late PRC state chairman Li Xiannian, who had once served as mayor of Wuhan.[47]

In the summer of 2022, the state tacitly acknowledged the depth of clientelism and high-level corruption when it arrested or placed under investigation several officials who had long guided the implementation of its semiconductors policy, including Xiao Yaqing, former head of the Ministry of Industry and Information Technology (MIIT); Ding Wenwu, former president of the Big Fund and chief of the semiconductors policy department at MIIT; Lu Jun, former chief of Sino IC Capital, which manages the Big Fund; Ren Kai, a vice president of Sino IC Capital and a director of SMIC; Zhao Weiguo, former chairman of Tsinghua Unigroup and YMTC; and Diao Shijing, a former Tsinghua Unigroup copresident.[48] The details of each case may never fully emerge—but even beyond any personal culpability in the disappointing performance and scandals detailed above, their downfall and the patronage networks of senior political and military figures they were quietly connected to set off speculation about intrigue at the highest levels of power.[49]

Looking Ahead

The intensification of US export controls since 2018 has laid bare the gaps and vulnerabilities in China's semiconductor industry. If enforced strictly, US restrictions on lithography tools, EDA software, high-performance chips, and components will not only block the industry's ascent up the value chain but also degrade its current capabilities by hampering the performance, maintenance, and replacement of equipment already in the field. Employment restrictions on US citizens and green card holders—coupled with parallel measures by Taiwan and growing unease in Japan and Korea—promise to choke off imported talent where local capabilities are weakest: upper management, manufacturing, and R&D. The expanding roster of semiconductor companies on the Department of Commerce's Entity List, including SMIC (logic), YMTC (NAND), and Cambricon (artificial intelligence [AI] chips), will impair operations at some of China's flagship firms. The short- to medium-term impact of these measures will be devastating.

Nevertheless, Xi appears undaunted, and foreign pressure plays to his techno-nationalist instincts. As an illustration: Xi selected Jin Zhuanglong as the minister of industry and information technology in July 2022. Before assuming this post, Jin served as chairman of the Commercial Aircraft Corporation of China (COMAC), China's homegrown contender in the commercial aviation market against Airbus and Boeing, and as executive deputy director of the Office of the Central Military-Civilian Integration Development Commission, the body charged with coordinating China's policy of military-civil fusion. Jin's appointment, then, suggests that the state will take a more active role in the management of the semiconductor industry. It also implies that China may adopt a posture oriented toward national security considerations and great-power competition, not globalized cooperation.

The state continues to funnel copious resources into the semiconductor industry, and it is introducing new policies and refining old ones to manage present challenges. For example, up until now, PRC-based firms have been reluctant to settle for domestic semiconductor manufacturing equipment when superior foreign alternatives were available. In principle, recent US export controls hand much of the market back to indigenous suppliers, and the PRC government is reportedly preparing to subsidize this transition. China's equipment manufacturers will need to rise to this opportunity by developing the products their captive market demands.[50] Similarly, Shenzhen has drafted a plan to subsidize a move to domestic EDA tools, which trail their foreign competitors by a wide margin. The plan also funds the use of advanced IP cores in domestic chip designs, promotes R&D on advanced packaging techniques (such as chiplets), and subsidizes development on RISC-V (reduced instruction set computer "five"), a free and open instruction-set architecture that has attracted strong interest from PRC firms.[51] The promotion of domestic equipment and RISC-V reflects a broad effort to mitigate the risk of exposure to US technology by designing it out of supply chains. To the extent that foreign firms perceive a commercial advantage in facilitating that abatement, their interests may coincide with China's, eroding the effectiveness of US export controls and the position of US technology in the marketplace.

A suite of other initiatives is under way. PRC universities are at the forefront of fundamental research in semiconductor-related fields.[52] In 2022, the government began underwriting the costs of specialized schools for integrated circuits at Tsinghua University, Peking

University, and Huazhong University of Science and Technology; in cooperation with industry partners, these schools hope to foster the commercialization of basic research and teach practical skills. They aim to create pipelines for better-trained engineers and technicians to enter the industry and improve job placement and retention.

To bridge the gap between startups and national champions, the government has breathed new life into a program to support ten thousand "little giants" (小巨人) from among China's small and medium enterprises in strategically important sectors. Chastened by recent experience, this program seeks to prevent fraud by carefully screening applicants and tracking performance.[53] Regulators have also approved a surge of domestic initial public offerings (IPOs) that could improve the access of local firms in critical segments to capital. During the first eleven months of 2022, forty-six design, fabrication, components, and materials firms went public—compared to nineteen during the same period the year before.[54] Exchange-traded funds from firms such as ICBC Credit Suisse Asset Management and ChinaAMC allow international investors to participate in this market.

PRC-based firms are adapting creatively to the obstacles in their path. Some, for example, are concealing their successes to avoid unwanted scrutiny. Neither SMIC nor YMTC publicly announced their respective breakthroughs at the 7nm and 232-layer scales in 2022, feats that would have been celebrated loudly in years past. Instead, industry watchers discovered and analyzed the chips after they had entered the supply chain. Other firms, such as Alibaba and Biren, are throttling back the performance of their latest designs so that TSMC can continue to manufacture them without running afoul of US restrictions.[55]

Blocked from pursuing high-end manufacturing, the industry is shifting investment to trailing-edge logic and memory, which still account for the lion's share of global sales. Following the examples of solar panels, batteries, and telecommunications, a subsidized expansion of output in these categories could enable PRC firms to underprice foreign competitors and force them out of the market. If China succeeds in this gambit, it could starve foreign firms of the revenue that sustains the reinvestment in R&D needed to stay competitive over

Table 8.4. R&D as a Percentage of Sales (2020)

	UNITED STATES	EUROPE	JAPAN	CHINA	EMERGING MARKETS	GLOBAL
R&D as a percentage of sales	18.6%	17.1%	12.9%	6.8%	8.6%	13.7%

Source: Semiconductor Industry Association, 2021 State of the US Semiconductor Industry, September 2021, 18.

time; instead, that revenue would flow to China and finance the ascent of its own firms.

That strategy would play to China's strengths. To date, China's semiconductor industry has advanced with levels of R&D spending less than half the global average (table 8.4). While this model cannot support a bid for technological leadership, it can fund the establishment of a dominant position in mature technologies. Suppressing competition could slow innovation across the industry.[56]

Conclusion

Leadership and self-sufficiency in semiconductors are political goals without clear benchmarks. Yet Xi's determination to pursue them must not be underestimated, and his administration will bring to bear all the tools at its disposal, including diplomacy, IP theft, and espionage.

Semiconductors are market commodities for which reliability, costs, and features are paramount. Establishing technological leadership requires not just resources, discipline, and will, but also a model of development that fosters the organizational and cultural conditions to allocate inputs efficiently, innovate consistently at competitive prices, and earn the trust of clients. Self-sufficiency sets the bar still higher, suggesting not just a seamless indigenous production chain but also routine upgrades to it since the technology advances relentlessly.

By any measure, China's patchwork semiconductor industry is far from reaching these goals, and the hurdles before it are formidable. China's economy is slowing, the demographic and educational composition of its workforce is unfavorable, and the state is taking a firmer hand in the management of major technology firms, which may impair innovation and market discipline. Mercantilist policies, domestic repression, and rising geopolitical tensions are alienating foreign partners and amplifying calls to decenter China from global supply chains. And US export controls aim to halt China's advance by cutting off access to sought-after technology, equipment, and talent.

Against such headwinds, China may be able to bootstrap itself into a volume leader of mature products such as trailing-edge memory and logic. This feat alone would give China new leverage in its rivalry with the United States by establishing a chokehold on chips used in a wide array of products, including consumer goods, medical devices, automobiles, industrial systems, and military platforms. But absent breakthroughs that enable China's firms to leapfrog competitors—or state subsidies sufficient to cripple competitors—attaining broad self-sufficiency or leadership in semiconductors will likely remain out of reach for the foreseeable future.

NOTES

1. Semiconductor Industry Association, 2022 Factbook, 13.
2. IC Insights, "China-Based IC Production to Represent 21.2% of China IC Market in 2026."
3. Semiconductor Industry Association, "US Needs Greater Semiconductor Manufacturing Incentives," July 24, 2020.
4. Alex Capri, "China's Microchip Ambitions: Semiconductors Advance the Next Phase of Techno-Nationalism," Hinrich Foundation, June 22, 2021.
5. *Xinhua*, 习近平主持召开中央全面深化改革委员会第二十七次会议强调 健全关键核心技术攻关新型举国体制 全面加强资源节约工作 [Xi Jinping Presided over the 27th Meeting of the Central Committee for Comprehensively Deepening Reform, Stressed Improvement of the New Type Whole-Nation System of Core Research and Development, and Comprehensively Strengthening of the Work of Resource Conservation], September 6, 2022, http://www.news.cn/politics/leaders/2022-09/06/c_1128981539.htm; Max J. Zenglein and Anna Holzmann, "Evolving Made in China 2025: China's Industrial Policy in the Quest for Global Leadership," MERICS, July 2, 2019.
6. For instance, National Development and Reform Commission, "高技术产业化"十一五"规划 [11th Five-Year Plan for High-Technology

Industrialization],” April 10, 2008, http://www.mofcom.gov.cn/aarticle/b/g/200804/20080405470382.html.

7. Douglas Fuller, “Growth, Upgrading, and Limited Catch-Up in China’s Semiconductor Industry,” in *Policy, Regulation, and Innovation in China’s Electricity and Telecom Industries*, edited by Loren Brandt and Thomas G. Rawski (New York: Cambridge University Press, 2019), 267–79; John VerWay, “Chinese Semiconductor Industrial Policy: Past and Present,” *Journal of International Commerce and Economics*, July 2019, 9–12.
8. State Council, 国家中长期科学和技术发展规划纲 (2006–2020), December 20, 2005, http://www.gov.cn/gongbao/content/2006/content_240244.htm.
9. State Council, “《国家集成电路产业发展推进纲要》正式公布 [Guideline for the Promotion of the Development of the National Integrated Circuit Industry Officially Promulgated],” China Semiconductor Industry Association, October 30, 2019, http://www.csia.net.cn/Article/ShowInfo.asp?InfoID=88343.
10. Eastmoney Securities, “东方财富证券 [The First Phase of Fundraising Bears Fruit, The Second Phase is About to Begin],” 大基金一期投资硕果累累,二期蓄势待发, December 31, 2019, p. 9, https://pdf.dfcfw.com/pdf/H3_AP201912311373119321_1.pdf?1577789587000.pdf.
11. State Council of the PRC, “中华人民共和国国民经济和社会发展第十四个五年规划和2035年远景目标纲要 [Outline of the 14th Five-Year Plan and 2035 Vision for National Economic and Social Development of the PRC],” March 12, 2021, http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm.
12. Beijing Municipal People’s Government, “北京市国民经济和社会发展第十四个 五年规划和二〇三五年远景目标纲要 [Outline of the 14th Five-Year Plan and 2035 Vision for the National Economic and Social Development of Beijing],” January 27, 2021, http://fgw.beijing.gov.cn/fgwzwgk/zcgk/ghjhwb/wnjh/202104/P020220614554396990009.pdf; Shanghai Municipal People’s Government, 上海市国民经济和社会发展第十四个五年规划 和二〇三五年远景目标纲要 [Outline of the 14th Five-Year Plan and 2035 Vision for the National Economic and Social Development of Shanghai],” January 27, 2021, https://www.shanghai.gov.cn/cmsres/8c/8c8fa1641d9f4807a6897a8c243d96ec/c70c2c6673ae425efd7c11f0502c3ee9.pdf; Zhejiang Province Development and Reform Commission, “浙江省国民经济和社会发展第十四个五年 规划和二〇三五年远景目标纲要 [Outline of the 14th Five-Year Plan and 2035 Vision for the National Economic and Social Development of Zhejiang Province],” February 23, 2021, https://zjjcmspublic.oss-cn-hangzhou-zwynet-d01-a.internet.cloud.zj.gov.cn/jcms_files/jcms1/web3185/site/attach/0/6abf4850723f40ce863f0a7d517072b4.pdf.
13. Semiconductor Industry Association, *SIA Whitepaper: Taking Stock of China’s Semiconductor Industry*, July 2021, 3.

14. OECD Trade Policy Papers, *Measuring Distortions in International Markets: The Semiconductor Value Chain*, No. 234, December 12, 2019, p. 8.
15. Stephen Ezell, "Moore's Law under Attack: The Impact of China's Policies on Global Semiconductor Innovation," ITIF, February 18, 2021, p. 22, https://itif.org/publications/2021/02/18/moores-law-under-attack-impact-chinas-policies-global-semiconductor/.
16. Antonio Varas, Raj Varadarajan, Jimmy Goodrich, and Falan Yinug, *Government Incentives and US Competitiveness in Semiconductor Manufacturing* (Boston, MA: Boston Consulting Group and Semiconductor Industry Association, September 2020), 1.
17. Semiconductor Industry Association, *SIA Whitepaper*, 3; Tianlei Huang, "Government-Guided Funds in China: Financing Vehicles for State Industrial Policy," Peterson Institute for International Economics, June 17, 2019; Yifan Wei, Yuen Yuen Ang, and Nan Jia, "The Promise and Pitfalls of Government Guidance Funds," June 21, 2022, abstract available at https://ssrn.com/abstract=3812796.
18. *Xinhua*, "十四五"先进制造业集群发展蓝图酝酿待出 [The Blueprint for the Development of Advanced Manufacturing Clusters in the '14th Five-Year Plan' Is Brewing and Ready to Come Out]," March 23, 2021, http://www.xinhuanet.com/techpro/2021-03/23/c_1127243005.htm; PRC Ministry of Industry and Information Technology, "先进制造业集群决赛优胜者名单公示 [Advanced Manufacturing Cluster Finalist List Announcement]," March 22, 2021, https://www.miit.gov.cn/jgsj/ghs/gzdt/art/2021/art_c59a0995a34d4c26a850faae580f0544.html.
19. Wei Sheng, "Where China Is Investing in Semiconductors, in Charts," TechNode, March 4, 2021.
20. Semiconductor Industry Association, *SIA Whitepaper*, 5.
21. Kensaku Ihara, "Taiwan Loses 3,000 Chip Engineers to 'Made in China 2025,'" *Nikkei Asia*, December 3, 2019.
22. Capacity is in terms of potential water starts per month, not necessarily outputs or value created. See Semiconductor Industry Association, *SIA Whitepaper*, 2.
23. Thomas Alsop, "Leading Semiconductor Foundries Revenue Share Worldwide from 2019 to 2022, by Quarter," Statista, June 20, 2022.
24. Dylan Patel, "2022 NAND–Process Technology Comparison, China's YMTC Shipping Densest NAND, Chips 4 Alliance, Long-Term Financial Outlook," *SemiAnalysis*, August 12, 2022.
25. Qianer Liu and Eleanor Olcott, "China's Chip Darling YMTC Thrust into Spotlight by US Export Controls," *Financial Times*, October 13, 2022.
26. IC Insights, "Top Suppliers Enjoy Big Gains in Small NOR Flash Market," June 21, 2022.

27. Dylan Patel, "Meet NETINT: The Startup Selling Datacenter VPUs to ByteDance, Baidu, Tencent, Alibaba, and More," *SemiAnalysis*, August 14, 2022.
28. For example, a US Cybersecurity and Infrastructure Security Agency (CISA) advisory in September 2022 pointed to a hard-coded backdoor password within a GPS chip used by motorcyclists produced by Shanghai-based MiCODUS that allowed for unpermitted access to location tracking. See Alexi Drew, "Chinese Technology in the 'Internet of Things' Poses a New Threat to the West," *Financial Times*, August 10, 2022.
29. Mathieu Duchâtel, *The Weak Links in China's Drive for Semiconductors*, Institut Montaigne (Paris: January 2021).
30. IC Insights, "China Forecast to Fall Far Short of Its 'Made in China 2025' Goals for ICs," January 6, 2021.
31. Scott Fulton III, "Arm Processors: Everything You Need to Know Now," *ZD Net*, March 30, 2021.
32. Will Hunt, Saif M. Khan, and Dahlia Peterson, "China's Progress in Semiconductor Manufacturing Equipment: Accelerants and Policy Implications," Center for Security and Emerging Technology, March 2021.
33. Julie Zhu, "Exclusive: China Readying $143 billion Package for Its Chip Firms in Face of US Curbs," Reuters, December 13, 2022.
34. "Implementation of Certain 2021 Wassenaar Arrangement Decisions on Four Section 1758 Technologies," *Federal Register* 87, no. 156, August 15, 2022, 49979–49986; "Revisions to the Unverified List: Clarifications to Activities and Criteria that May Lead to Additions to the Entity List," *Federal Register* 87, no. 197, October 13, 2022, 61971–61977.
35. IC Insights, "China-Based IC Production to Represent 21.2% of China IC Market in 2026," May 18, 2022; IC Insights, "China Forecast to Fall Far Short of Its 'Made in China 2025' Goals for ICs."
36. General Administration of Customs of the PRC, "2021年12月进口主要商品量值表(美元值) [December 2021 Table of Imports of Major Commodities in Terms of Volume and Value (in Dollars)]," January 18, 2022, http://www.customs.gov.cn/customs/302249/zfxxgk/2799825/302274; General Administration of Customs of the PRC, "2021年12月出口主要商品量值表(人民币值) [December 2021 Table of Exports of Major Commodities in Terms of Volume and Value (in RMB)]," January 18, 2022, http://www.customs.gov.cn/customs/302249/zfxxgk/2799825/302274. The Internal Revenue Service's average currency conversion rate for 2021 of 6.452 RMB to the dollar was applied.
37. Semiconductor Industry Association, *SIA Whitepaper*.
38. IC Insights, "China Forecast to Fall Far Short of Its 'Made in China 2025' Goals for ICs."
39. Jin Yezi, "集成电路人才缺口仍超20万，这些岗位最紧缺 [Integrated Circuit Talent Shortfall Still Exceeds 200,000, These Positions Are in the Shortest

Supply]," *Sina*, October 29, 2019, https://finance.sina.com.cn/roll/2021-10-29/doc-iktzscyy2370774.shtml.
40. Sheng, "Where China Is Investing in Semiconductors"; Mark Lapedus, "China Accelerates Foundry, Power Semi Efforts," *Semiconductor Engineering*, November 22, 2021.
41. John Lee and Jan-Peter Kleinhans, *Mapping China's Semiconductor Ecosystem in Global Context: Strategic Dimensions and Conclusions*, Stiftung Neue Verantwortung and MERICS, June 2021, 40–51.
42. Song Jie and Guo Fang, "大跃进与烂尾潮同现 国产芯片路在何方? [Great Leap Forward and Rotten Tide at the Same Time: Where Does the Domestic Chip Road Lie?]," *China Economic Weekly*, November 2, 2020, 44–48, http://www.ceweekly.cn/2020/1102/318726.shtml.
43. Wei Sheng, "HSMC Promised China's First 7nm Chips: It Didn't Go Well," *TechNode*, September 9, 2020.
44. Sidney Leng, "US Semiconductor Giant Shuts China Factory Hailed as 'a Miracle,' in Blow to Beijing's Chip Plans," *South China Morning Post*, May 20, 2020; Emily Feng, "A Cautionary Tale for China's Ambitious Chipmakers," NPR, March 25, 2021.
45. Che Pan, "China's Tsinghua Unigroup Completes Debt Restructuring, Ownership Change to Keep Afloat Its Major Semiconductor Operations," *South China Morning Post*, July 12, 2022.
46. Joanne Lee-Young, "Analysis: The Digital Prince of China," CNN, March 6, 2001.
47. *Securities Times*, "千亿武汉弘芯:空壳股东障眼法"芯骗"团伙钻产业空子 [Hundred Billion Wuhan Hongxin: Shell Shareholders Cover Up 'Core Fraud,' Gang Exploits Industry Loopholes]," September 25, 2020, https://archive.ph/Zqliz.
48. Li Yuan, "Xi Jinping's Vision for Tech Self-Reliance in China Runs into Reality," *New York Times*, August 22, 2022.
49. Dan Macklin, "What's Driving China's Chip Sector Crackdown," *The Diplomat*, August 29, 2022.
50. Zhu, "Exclusive: China Readying $143 Billion Package."
51. Justice Bureau of Shenzhen Municipality, "深圳市关于促进半导体与集成电路产业高质量发展的若干措施 (征求意见稿) [Several Measures of Shenzhen City for the Promotion of High-Quality Development in the Semiconductor and Integrated Circuit Industry (Draft for Comment)]," October 8, 2022, http://sf.sz.gov.cn/ztzl/gfxwj/gfxwjyjzj_171008/content/mpost_10156478.html.
52. Takeshi Hattori, "ISSCC 2023 、論文採択件数で中国が北米を抜いて史上初の首位に [ISSCC 2023: China Surpassed North America in the Number of Papers Adopted for the First Time in History]," Tech+ , November 21, 2022, https://news.mynavi.jp/techplus/article/20221121-2519134/.

53. Coco Feng, "China Has Named Nearly 9,000 'Little Giants' in Push to Preference Home-Grown Technologies from Smaller Companies," *South China Morning Post*, September 9, 2022; Ministry of Industry and Information Technology, "工业和信息化部办公厅关于开展第四批专精特新"小巨人"企业培育和第一批专精特新"小巨人"企业复核工作的通知 [Notice of the General Officer of the Ministry of Industry and Information Technology on the Cultivation of the Fourth Batch of Specialized New 'Little Giant' Enterprises and the Review of the First Batch of Specialißzed New 'Little Giant' Enterprises]," Enterprise Letter no. 133, May 15, 2022, https://www.miit.gov.cn/jgsj/qyj/wjfb/art/2022/art_9d88f62a3c5d47bd8698e84d7a486274.html.
54. Che Pan and Ann Cao, "Tech War: Fresh Funding Pipeline Enables China's Sanctions-Hit Semiconductor Industry to Cope with Latest US Trade Restrictions," *South China Morning Post*, November 27, 2022.
55. Qianer Liu, Ryan McMorrow, Nian Liu, and Kathrine Hill, "Chinese Chip Designers Slow Down Processors to Dodge US Sanctions," *Financial Times*, November 6, 2022.
56. Ezell, "Moore's Law under Attack."

A report of the Working Group on
Semiconductors and the Security of the
United States and Taiwan, a joint project of
the Hoover Institution and the Asia Society
Center on U.S.-China Relations