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Learning the Superior Techniques of the Barbarians

China's Pursuit of Semiconductor Independence

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James A. Lewis

CSIS | CENTER FOR STRATEGIC & INTERNATIONAL STUDIES

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CSIS TECHNOLOGY POLICY PROGRAM and
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CIPS is managed by the Freeman Chair in China Studies in cooperation with the Technology Policy Program at CSIS. The report authors are: Scott Kennedy, deputy director of CSIS's Freeman Chair in China Studies and director of the Project on Chinese Business and Political Economy; James A. Lewis, senior vice president at CSIS; Samm Sacks, former senior fellow in the Technology Policy Program; and Will Carter, deputy director and fellow in the Technology Policy Program. Research support is headed by Qiu Mingda of the Freeman Chair in China Studies.

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Executive Summary

While China has made immense investments in science and technology, and while these are producing results, it is still dependent on Western technology. This is particularly true for semiconductors. China's dependence on foreign semiconductors has worried Beijing for decades. China suspects that Western semiconductors contain "backdoors," intentional vulnerabilities that can be exploited for intelligence and military purposes. In 2016, President Xi Jinping said, "the fact that core technology is controlled by others is our greatest hidden danger." Vice Premier Ma Kai said at the 2018 National People's Congress, "We cannot be reliant on foreign chips."[1] China intends to end this dependence, but despite 40 years of investment and espionage, it is unable to make advanced semiconductors. Along the way, there have been embarrassing frauds and expensive failures.

Mistaken Expectations

Since 1979, China has used hefty state investments in infrastructure, education, and research, along with technology acquisitions and supportive business policies, to produce incredible economic growth. Western companies were happy to take advantage of the Chinese market and for many it became essential. Expectations that concessions made to China would be only temporary, needed only until it became a market economy, were a serious miscalculation. No one objects to China's growth and modernization. The problem lies with the means the Chinese government uses to achieve this, including espionage, intellectual property (IP) theft, coercive joint venture requirements, trade barriers, and aggressive mercantilist policies.

China is a Net Tech Importer

China remains a net importer of technology. China wants to move "up the value chain" from assembling final products from imported components to creating advanced technology in China itself, but imports of chips and technology will be the norm for many years to come.

Today, only 16 percent of the semiconductors used in China are produced in-country, and only half of these are made by Chinese firms. It is dependent on foreign suppliers for

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1. Xi Jinping, "Speech at the Work Conference for Cybersecurity and Informatization," (speech, Beijing, April 2016); Bob Davis and Eva Dou, "China's Next Target: U.S. Microchip Hegemony," https://www.wsj.com/articles/chinas-next-target-u-s-microchip-hegemony-1501168303.

advanced chips. China aims to produce 40 percent of the semiconductors it uses by 2020 and 70 percent by 2025.

"China 2025" has become a catchphrase for China's aggressive industrial policy and something of a hobgoblin for policy-makers, but we should not take yet another report by Chinese planners too seriously. China routinely cranks out economic plans; what counts is not the plan but the money. The total planned investment in semiconductors is $118 billion over five years, including $60 billion from provincial and municipal governments (although government investments in China can suffer from politicization and corruption). For comparison, leading Western firms also invest billions annually in research and development (R&D). Intel invests over $13 billion while Samsung and Qualcomm invested over $3 billion each. Huawei spends about $15 billion and ZTE about $1.9 billion.

Another Round of Massive Investment in Semiconductors

In 2014, China's State Council set the goal of becoming a global leader in all segments of the semiconductor industry by 2030. "Made in China 2025" reiterated this, but chips are not an easy market to break into, something that has hampered China's previous efforts. China spent billions of dollars in earlier decades to create a domestic semiconductor industry but with little success. The chief difficulty for Chinese firms is not access to equipment but their lack of experience and "know-how." This continues to be a problem. China's pursuit of indigenous industries also runs counter to the trend toward globally integrated supply chains, which are the most efficient in production and innovation. An indigenous industry, even when supported by espionage and subsidies, will remain second-best in a globally integrated innovation system.

Despite Western restrictions on technology transfer, there are avenues that China can take to gain semiconductor independence. The first is through drawing technology from Taiwan. Second, China can take advantage of "fabless" semiconductor production, where Chinese firms design chips but the manufacturing processes are handled by specialist companies like the Taiwanese Semiconductor Manufacturing Company (TSMC). Finally, China can try again to build a state-funded, indigenous industry. Chinese companies prefer fabless chip production, while the government-preferred solution of building domestic semiconductor fabrication facilities (fabs) is expensive and risky.

China Innovation at Risk

The long-standing debate about whether China could become an innovation power appears to be over (with two significant caveats). The first is that successful Chinese innovation is still limited by the country's relative technological backwardness. The second caveat is that Chinese innovation blossomed in a period of relative political openness. Now that openness is shrinking under Xi Jinping and has been accompanied by greater state economic direction, it is possible that the trend of increasing Chinese innovation will slow or reverse.

Market Versus State

Both China and the United States have advantages and disadvantages in what is a contest over governance as well as investment and research. The multinational nature of research

and innovation complicates any national competition for technological leadership and will create forces that both states will find difficult to control. A globally-oriented U.S. industry may have an advantage over a nationally-focused China.

China's technology sector has vulnerabilities. Centrally-directed economies are less efficient, since government policy supplants market signals on where to invest. Easy access to credit allows inefficient firms to survive, draining resources from more productive activities. Previous rounds of semiconductor investment in China saw new firms (often funded by provincial or municipal governments) close after a few years.

This support from the government support means that Chinese companies can continue to operate even when they are unprofitable, inflicting damage on both the Chinese economy and the economies of other nations. Han Yinhe of the Chinese Academy of Sciences calls this "chaotic competition." China's government-subsidized expansion will squeeze semiconductor firms in other countries, shrinking their income and numbers and reducing the ability of semiconductor producers to invest in R&D. The overall effect of China's investments will be to weaken the global industry and slow the pace of semiconductor innovation.

The Perils of Techno-Triumphalism

Debate is distorted by the Chinese government's propensity to exaggerate its technological prowess. This is part of the triumphalist narrative about China's return to the center of the world stage. In reality the story is more nuanced, with China leading in a few areas (such as biotechnology, where Chinese firms face fewer regulatory hurdles) and lagging in many others.

Nineteenth century Chinese reformers asked whether it was possible to absorb Western technology without also absorbing Western political ideas. At the risk of tremendous oversimplification, the answer was ultimately no. China's Communist Party faces a similar problem, but with greatly enhanced tools of social control and surveillance, it expects to avoid a similar fate.

How Should the United States Respond?

Semiconductors and microelectronics are part of interdependent manufacturing network centered on the Pacific Rim. Disentangling this integrated supply chain, created under more favorable political conditions, will be difficult for the United States, since many U.S. chip companies either have facilities in China or rely on Chinese companies for lower level functions like testing. Interdependence will also hamper China's efforts to build a national industry, since competitive advantage lies with the internationally distributed supply chains (described by the industry as "horizontal segmentation").

Given past Chinese practice, we can safely assume that if China achieves a dominant position in semiconductors it will use it for intelligence, military, commercial, and political advantage. The most damaging effect of Chinese overinvestment is to undercut research and innovation in semiconductors by reducing the revenue flows to innovative chip companies that fund R&D.

Semiconductors are the backbone of the digital economy. The U.S. semiconductor industry and national security are closely linked. The United States will need to engage China to

change its mercantilist behavior while simultaneously taking steps to strengthen the U.S. semiconductor industry. Changing Chinese behavior will be difficult but not impossible if the United States and its allies take a consistent approach. In the near term, policy should focus on blunting Chinese investments in production and design technology regulations and increased counterespionage programs. U.S. technological strength can be reinforced by investing more in basic science and government research and taking a more assertive approach to contesting foreign regulations used to gain unfair advantage.

China's Pursuit of Semiconductor Independence

China's rise is the greatest strategic problem of this century. Some say that if the twentieth century was the American Century, the twenty-first century will be China's. Perhaps so, but China has a long way to go. The ruling Chinese Communist Party (CCP), the last of the great Leninist parties, sets 2049 as the goal for China to become a fully developed nation.

China's policies and official attitudes toward the United States have evolved significantly over the last 40 years. The current rulers of China see one major obstacle to China's rise—the United States—and Chinese policy is directed at displacing the United States, its companies, and its allies. The United States has not faced a hostile strategic competitor since 1989 and the 30-year stretch of peace and unchallenged leadership left it unprepared for the new contest.

Unprepared because the terms of this contest are different. China does not seek territorial expansion or, for the most part, global adoption of some Chinese ideology (although it seeks to replace the dominant global narrative of Western democratic values with some combination of statist economics and global institutions "with Chinese characteristics"). Xi Jinping has said China's goal is to "champion and apply a new vision of global governance," a vision more favorable to China and continued CCP rule.

Technological leadership is a key part of this contest. Technology is a crucial source of U.S. power. The Chinese have studied how technological leadership has advanced U.S. power and now seek to duplicate U.S. technological strength. The CCP fears that U.S. technological dominance—particularly in information technology (IT), given its ability to shape opinion and politics—creates existential risk for continued party rule. Since opening to the West, Chinese policy has sought to gain the security and economic benefits of IT while minimizing political risk. Creating indigenous IT products is an important part of this effort.

China's leaders are eager to move away from their dependency on foreign technology. Chinese planners[2]—and this is a country where government economic planning can be more important than the market—expects this task will take decades. China has made immense investments in programs to build its science and technology base, and while these are beginning to produce results, China is still dependent on Western technology.

2. See Appendix for a list of China's many semiconductor plans and initiatives from 1956 to 2018.

China has both security and commercial motives in developing its semiconductor industry. The recent experience with the ban on U.S. technology going to ZTE, one of China's leading telecommunications equipment producers, reinforced this for China. China discovered that it is completely reliant on U.S. semiconductor technology. The ban was a near death experience that led China to accelerate its efforts to build an indigenous chip industry. One exuberant commenter said, "One ZTE falls, and thousands of Chinese chip companies will stand up!"[3]

But despite 40 years of effort, investment, and espionage, China is unable to make advanced semiconductors.[4] There have been embarrassing frauds, as when a Chinese entrepreneur claimed to have made an advanced chip but was found to have filed off the serial number of American chips and replaced it with his own, and expensive failures, such as the centrally directed programs of the early 2000s that wasted billions of dollars in building unproductive semiconductor fabrication facilities (fabs). The complex chip architectures and precise production processes that go into chip-making are not easily duplicated.

China's dependence on foreign semiconductors has concerned Beijing for decades. Qian Xuesen, a leading figure in Chinese strategic weapons development, said, "we gained a lot through developing 'two bombs, one satellite' in 1960s; we lost a lot because we didn't develop semiconductor in 1970s."[5] Beijing has spent billions to remedy this, but China still lags in this sector. China again intends to end its dependence and reshape the global semiconductor market to give its companies a leading position. This is part of President Xi Jinping's larger goal to make China the world's largest economy, a global leader in technology, and a dominant force in global governance—all under tight CCP control.[6] Gaining a dominant position in semiconductors is part of this larger strategy for "the great rejuvenation of the Chinese nation."

China's state-led semiconductor push creates major issues for its trade partners. It distorts China's domestic technology market and creates capital misallocations that a debt-laden China does not need. The state-financed and -directed investment program will damage the system of world trade rules and leave open the question of China's integration into global affairs.

It is reasonable, given past Chinese practice, to assume that if China achieves a dominant position, it will use it for intelligence, military, commercial, and political advantage by manipulating the semiconductor supply chains that Western economies and militaries depend upon. Memory chips, which can be easier to make, are the most vulnerable sector for subsidized Chinese competition and are the first target for Chinese acquisitions and investments in what the Chinese hope will be an upward path leading to the most sophisticated semiconductors.

However, the greatest risk from Chinese semiconductor policy comes from its market distorting effects. China's government-subsidized expansion in semiconductor

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3. David Bandurski, "Chip Claim Fuels Tech Exuberance, Again," China Media Project, http://chinamediaproject.org/2018/08/17/chip-claim-fuels-tech-exuberance-again/.
4. Chips that have higher performance and functionality resulting from the use of complicated "architectures" and cutting-edge design and manufacturing techniques that China will find difficult to duplicate.
5. An MIT graduate who worked on American missile programs, Qian was arrested in the 1950s and ultimately exchanged for American POWs held in Korea.
6. Robert Hannigan, "Wake up to the risks in Chinese tech dominance," *Financial Times*, July 27, 2018, https://www.ft.com/content/233f7dce-9013-11e8-9609-3d3b945e78cf.

manufacturing and design will squeeze semiconductor producers in other countries, reducing their income and numbers. The most damaging result from Chinese overinvestment might be to undercut further research and innovation in semiconductors by weakening the ability of leading semiconductor producers to invest in research and development (R&D). Semiconductor producers outside of China will come under increasing pressure, and the overall effect of China's investment will ultimately be to weaken the global industry and the pace of semiconductor innovation. China's goal is to challenge and then displace Western firms and to gain international leadership, but intent alone does not guarantee success.

Mistaken Expectations for China

Semiconductors and other advanced technologies are more than a commercial issue for China. China's defeat in the first Opium War was a shocking reversal for Chinese elites and still plays an important part of the CCP narrative of national resurgence.[7] For the Chinese, the desire to build their own technology dates back to the nineteenth century, when Chinese reformers concluded that technological leadership explained Western success. Restoring Chinese sovereignty and recovering China's global status requires first acquiring Western technology and then surpassing the West in creating new technologies.

As an aside, these nineteenth century Chinese reformers faced the question of whether it was possible to absorb Western technology without also absorbing Western political ideas. Could a modern technological base and global trading system be grafted onto the imperial system? At the risk of tremendous oversimplification, the answer was ultimately no, and the empire collapsed. The question is still salient as the CCP faces a similar problem. But with greatly enhanced tools of social control and surveillance, it expects to avoid a similar fate.

Partnerships with Western firms, accompanied by espionage and forced technology transfer, has made China better at absorbing western technology. In a few technology sectors, such as telecommunications, China can now make world-class products and, in combination with its mercantilist industrial policies, is on a path to achieve a dominant position. In other tech sectors, including semiconductors, China remains behind, unable to make high-end technologies, but using industrial policies and investments, it hopes to change this.

Under Deng's opening to the West, and in combination with heavy state investment in the economy, education, research, and supportive business policies, China has made incredibly rapid progress. A fundamental part of Deng's opening was the acquisition of Western technology, by sending Chinese students to the West, through partnerships with Western firms (trading technology for market access), and, in many cases, through espionage. Beginning with Deng, China has expanded its use of coercive and illicit activities to gain commercial and technological advantage.

Western companies were happy to take advantage of the opening of the China market, and for many it became an essential, even addictive, part of revenue growth. Government spending on education and R&D through government programs provides an incentive for

7. Ralph Jennings, "China Looks to Chip Away At Taiwan's Semiconductor Dominance," *Forbes*, November 9, 2017, https://www.forbes.com/sites/ralphjennings/2017/11/09/an-upstart-upstream-high-tech-sector-in-china-threatens-now-dominant-taiwan/#54699b035930.

foreign firms to locate in China.[8] Semiconductor manufacturers locate production centers in different countries to be close to customers or take advantage of business conditions. This explains much of the Western presence in China. But the early expectations that concessions made to China would be only temporary, as it moved towards becoming a market economy following an opening to international trade and business practices, were a serious miscalculation by Western governments and companies. However, it was a view that was almost universally shared. There was even internal debate in China about which direction—simplistically portrayed as "nationalist" versus "global"— would best serve China's interests.

That debate is over, and the "globalists" lost. China intends to reshape global norms to its advantage. Ironically, it is possible that if China was a market economy rather than a state-directed one, it might grow faster, and Chinese companies might do better in the global market. Left to themselves, Chinese companies would behave much as companies in other countries, but under CCP direction, they are a tool of the state.

When China opened its economy to Western companies, companies believed that the risk from technology transfer was acceptable, that there was a necessary cost of doing business in the world's fastest growing market, and that they could minimize any loss. Near-term gains for individual firms outweighed long-term costs, and there was an assumption that Western companies could compensate for IP losses by "running faster." Western companies employ a number of stratagems to reduce the risk of IP loss. These include holding back key processes from Chinese employees and allowing access only to low-end technologies, retaining advanced functions outside of China, and adopting a range of security measures. Western concerns were increased by the absence of adequate IP protection. Fear over the loss of IP is a disincentive to invest in China. An informal poll of Western semiconductor firms found that many had decided against locating in China because of IP theft concerns, and those that chose to locate in China have taken steps to safeguard their IP, particularly for design and manufacturing processes.

Semiconductors as a Foundational Technology

China's leaders regard semiconductors as a key strategic industry. Semiconductors are the backbone of the digital economy. Consumer and industrial applications rely on semiconductors. The production of semiconductors is based on a complex global supply chain combining both large companies and many smaller firms. The industry itself is about 60 years old, growing out of discoveries at American labs that found that copper lines etched into silicon wafers could take the place of bulky transistors (just as transistors replaced even bulkier vacuum tubes). The trend in the industry has been to cram more lines onto a single chip, specialize chips for specific functions (such as gaming or artificial intelligence), and to expand the number of actions a chip can perform as well as the speed at which it can perform them.

Semiconductor production is at the leading edge of physics and materials science, as manufacturers cram more computing power, memory, or functions onto a single chip. Many people are familiar with "Moore's Law." Moore's Law accurately predicted that

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8. Xueying Han and Richard P. Appelbaum, "China's science, technology, engineering, and mathematics (STEM) research environment: A snapshot," *PLoS ONE* 13, no. 4 (April 2018), https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0195347.

semiconductor processor speeds, or overall processing power, would double every two years, and there has been speculation for several years that we are reaching the end of the Moore's Law increases. Some expect to see a slowing, or even an end, to the industry's ability to cram more computing power onto a single chip.

Steps in Semiconductor Fabrication
Manufacturing a semiconductor can require more than 400 steps, and can take up to 2 months.[9] Manufacturing can be divided into six phases:
Research: Engineers and scientists develop new materials, new processing techniques, and new architectures to enable better chip performance.
Design: Engineers map out the electronic circuit patterns to be etched onto silicon wafers.
Wafer Production: Semiconductors are made from thin wafers of highly-pure silicon, grown under tightly controlled conditions before being sliced, cleaned, and polished.
Processing: The circuit pattern is then drawn on the wafers by applying thin layers of material on top of the wafer, "doping" to improve electrical properties, and photolithography to etch away material around the circuits.
Packaging: Individual circuits are cut from the wafer and mounted in a specially-designed casing that protects the chip while allowing it to connect to a circuit board.
Testing: Although examinations are performed at every stage of the fabrication process, rigorous testing for semiconductors occurs just before shipping. This testing covers the full range of chip functionality and connectivity and can take several weeks to complete.
Distribution: Chips are then shipped to resellers or manufacturers who integrate them into end devices.

Whether we are finally reaching the end or not, each new generation of chips creates more difficult technical production challenges and entails greater cost. The semiconductor industry's heavy investment in R&D has allowed the rapid rate of improvement to continue until now. The end of Moore's Law increases the importance of private-sector R&D (semiconductor companies are among the leading R&D investors in the United States and major firms routinely spend billions annually) and government investment in basic research for physical and material science, which helps drive improvements in chip performance.

R&D plays an essential role in staying competitive in the semiconductor industry and this is one area where China may eventually gain an advantage, given its decades-long investment in Science, Technology, Engineering, and Mathematics (STEM). Currently, no Chinese company is in the top 10 in spending on semiconductor R&D (although two Taiwanese companies make the list).[10] Four U.S. companies account for 57 percent of industry R&D spending (Intel by itself spends more than a third of total industry R&D spending). Chinese private sector R&D receives government support, a potential source of advantage, but the United States has similar programs, such as the Defence Advanced Research Projects Agency's (DARPA) multi-year, $1.5 billion project called the Electronics Resurgence Initiative, as well as other programs intended to develop technologies that

9. "2. Semiconductor – Metrology and Inspection," in Hitachi Commentary Sites "Semiconductor Room," https://www.hitachi-hightech.com/global/products/device/semiconductor/metrology-inspection.html.
10. Peter Clarke, "18 chip companies over $1bn in 2017 R&D spending," eeNews Analog, February 19, 2018, http://www.eenewsanalog.com/news/18-chip-companies-over-1bn-2017-rd-spending.

would revolutionize chip production and performance. The key difference is that DARPA funds research, not companies.

The cost and complexity of semiconductors varies widely according to their function. The market for chips has changed significantly as the range of digital and connected devices has increased. The basic categories of chips are logic, memory, sensors, power, signal, and analog. Logic chips are the "brain" of modern computing devices and are among the most complex chips to design and manufacture. China is not capable of making high end logic chips but has targeted memory chips as its entry point to the industry, the approach used by Taiwan and Korea.

One way to envision the market is to look at the chips crammed into a smart phone. High-end models can include up to twenty different chips for processing, memory, connectivity, navigation, and power management. Most of these are still produced in the United States, Taiwan, and Korea, but China as the world's biggest phone market (and after the ZTE experience) wants to make its own chips. This is also beyond China's current capabilities. The semiconductors in a single phone now provide computing and memory storage equal to the multi-million-dollar supercomputers of a few decades ago while also providing mobile connectivity.

Semiconductor Fabrication
The number of transistors packed onto a single chip has been the defining metric for semiconductors. As famously predicted by Moore's law, transistor density has doubled roughly every two years. More transistors mean chips can perform more operations.
Advanced chips today have more than 90 million transistors per millimeter[11]. This is possible because of steadily improving manufacturing processes that allowed increasingly smaller components to be drawn on silicon wafers. Today, transistors can be drawn at sizes of less than 20 nm, no more than a few dozen atoms in width.[12]
The current standard for wafer production ranges from 100-300 wafers per hour, with each wafer containing hundreds of individual chips.[13] Samsung's most advanced fab has reportedly achieved rates of 1,500 wafers per day.[14]
Manufacturers have increased the size of silicon wafers, allowing more chips per wafer. The largest wafers currently in production are 300 mm in diameter. Some companies have explored the production of 450 mm wafers, but the cost has so far discouraged the use of wafers this size.[15]

The market for chips is highly competitive, and production requires advanced and expensive scientific and manufacturing capabilities. Semiconductor manufacturing is a

11. Eric Martin, "Moore's Law is Alive and Well," Hacker Noon, December 21, 2018, https://hackernoon.com/moores-law-is-alive-and-well-adc010ea7a63.
12. David Manners, "Intel re-ignites node controversy," Electronics Weekly, April 23, 2018, https://www.electronicsweekly.com/news/business/intel-re-ignites-node-controversy-2018-04/.
13. "Roadmap Semiconductor Equipment 2018-2021," Holland High Tech, March 1, 2018, https://www.hollandhightech.nl/nationaal/innovatie/roadmaps/semiconductor-equipment.
14. Billy Tallis and Anton Shilov, "Samsung Starts Mass Production of Chips Using its 7nm EUV Process Tech," AnandTech, October 17, 2018, https://www.anandtech.com/show/13496/samsung-starts-mass-production-of-chips-using-its-7nm-euv-process-tech.
15. Joel Hruska, "450mm silicon wafers aren't happening any time soon as major consortium collapses," Extreme Tech, January 13, 2017, https://www.extremetech.com/computing/242699-450mm-silicon-wafers-arent-happening-time-soon-major-consortium-collapses.

complex process carried out at facilities that cost billions of dollars to construct and equip. A modern semiconductor fab can now cost between $7 billion and $14 billion to build and may be out of date after five or six years.

Semiconductor manufacturing equipment (SME)—the machines used to build semiconductors—are among the most technologically advanced industrial equipment in use and are closely related to advances made in physics as it involves operations at the molecular and atomic levels. Companies in Japan, Germany, the Netherlands, and the United States are the principle SME producers. China is dependent on foreign suppliers for manufacturing and testing equipment, something that is unlikely to change for years if it is prevented from buying a foreign producer outright.

Semiconductor manufacturing requires experience, ownership of (or access to) a substantial amount of IP, managerial skills, a highly-skilled workforce, and a close connection to scientific research. It also requires a close understanding of the market and the product in which the chip will ultimately be used, an area of "know-how" where China has lagged. Currently, the United States leads in chip design, followed by Taiwan. China's integrated circuit design sector continues to be the fastest growing part of China's semiconductor industry. Its revenues exceeded $20 billion for the first time in 2015 and has grown to represent 25 percent of the worldwide fabless industry. In 2017, China reportedly had 1,380 IC design companies (almost 90 percent of these had less than 100 employees).[16]

The industry is disaggregated, and few firms are vertical producers (meaning silicon sand goes in one end and chips come out the other). Increasingly, firms specialize in one phase of production. The production cycle for microprocessors begins with chip design. This is a complex and valuable part of microprocessor production that has become increasingly automated as chips have grown more complex. Specialized companies now license the use of circuit design tools and corresponding software libraries to chip developers for graphics, networking, and sensor chips. The ultimate design is sent to a foundry (semiconductor manufacturing company that makes chips using other people's designs). This fabless production has reshaped semiconductor manufacturing. Managing this complex supply chain is itself an essential skill (and another area of weakness for many Chinese firms).

Fabless manufacturing involves the customer designing the components but then contracting the actual manufacturing to another entity rather than acquiring its own manufacturing capabilities.

Fabless chipmakers design chips but do not manufacture them. Manufacturing is outsourced to a company that makes chips from other companies' designs. Many of these companies are in Taiwan and China, where skilled labor is plentiful. The fabless model is attractive, given the high cost of building a new fab, and it allows companies to invest in R&D while enjoying high production volumes. Two Chinese firms, HiSilicon (owned by Huawei) and Unigroup (51 percent-owned by Tsinghua University, which acts as an arm of government semiconductor investments), are among the leading fabless manufacturers (the U.S. firm Qualcomm remains the largest), but most Chinese "foundries" lag by several

16. Yorbe Zhang, "Heavy live coverage! Professor Wei Shaojun 2018 ICCAD speech compete PPT," EET China, November 16, 2011, https://www.eet-china.com/news/201711160900.html.

generations in state-of-the art production at volume.[17] Fabless chip production also circumvents a potentially huge obstacle to building a domestic industry—China's complete reliance on foreign sources for SME.

One of the best-known examples of this fabless model is ARM, a UK company (now owned by Softbank) whose designs for mobile telephony and other functions are widely used. ARM does not make chips, but its customizable designs are the basis of many other companies' products. ARM has over 300 partners, including HiSilicon and leading Western companies whose processors are based on ARM's designs.[18] The Chinese internet giant Alibaba is another example. It has acquired chip design companies and is using a fabless approach to design its own specialized chips for AI and for Internet of Things (IoT) devices.[19]

Semiconductor manufacturing has been reshaped by disaggregation, as firms divide along the stages in the manufacturing process into design houses, wafer production, foundries, assembly houses, and testing houses. This "horizontal segmentation" has led to a "fabless" approach to semiconductor manufacturing, which now accounts for about 17 percent of semiconductor production and continues to grow. Horizontal segmentation makes it easier for firms in China to find a place in the production cycle of the semiconductor industry.

Semiconductor Manufacturing Equipment
Semiconductor manufacturing is an extraordinarily capital-intensive enterprise. New fabs can cost between $6 billion to $20 billion, with equipment becoming outdated in five or six years.[20]
The equipment used for manufacturing semiconductors includes photolithography and etching systems, electron microscopes, equipment for measuring chip features, equipment for inspection and assembly for packaging chips, and testing equipment to verify chip quality.
Only a few western companies make this equipment. Most are American, but there is a large secondary market in refurbished SME.

The disaggregation of chip production and the increase in fabless chip production means that design, fabrication, and testing is spread among different countries, including China. China is more likely to develop indigenous chip supplies if it relies on Chinese design houses (of which there are more than 1,000) and then contracts out production to a dedicated semiconductor foundry, such as the Taiwan Semiconductor Manufacturing Company (TSMC). The dilemma so far for China in using a fabless approach is that these chips are designed to meet Chinese standards. This can make them less valuable for the global market.

17. Executive Office of the President, President's Council of Advisors on Science and Technology, *Report to the President: Ensuring Long-Term U.S. Leadership in Semiconductors* (Washington, DC: January 2017), https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/PCAST/pcast_ensuring_long-term_us_leadership_in_semiconductors.pdf.
18. Robert Triggs, "HiSilicon: What you need to know about Huawei's chip design unit," Android Authority, April 12, 2018, https://www.androidauthority.com/huawei-hisilicon-852231/.
19. Mark Began, "The U.S.-China Trade War Means Alibaba Is Producing Its Own Chips," Bloomberg Businessweek, October 25, 2018, https://www.bloomberg.com/news/articles/2018-10-25/the-u-s-china-trade-war-means-alibaba-is-producing-its-own-chips.
20. Colin Masson, "Why Services are the Future of Manufacturing," Microsoft, November 12, 2018, https://cloudblogs.microsoft.com/industry-blog/industry/manufacturing/why-services-are-the-future-of-manufacturing/; "TSMC says latest chip plant will cost around $20 bln," Reuters, December 7, 2017, https://www.reuters.com/article/tsmc-investment/tsmc-says-latest-chip-plant-will-cost-around-20-bln-idUSL3N1O737Z.

The ability to manage this global supply chain is one of the keys to profitability. Disentangling this integrated supply chain, created under different and more favorable political conditions, will be difficult if not impossible. This creates opportunities for China in the acquisition of semiconductor technology, but it also creates obstacles in trying to build a purely national industry since competitive advantage lies with the international supply chains. China is still dependent on foreign expertise for semiconductor production, particularly from Taiwan and the United States. Imports of both chips and technology will be the norm in China for many years to come.

According to SEMI's World Fab Forecast, China built 19 new semiconductor fabs after 2017. China's fab construction spending will reach record highs in 2018, reaching $6.2 billion and $6.8 billion, respectively, accounting for over 50 percent of worldwide construction spending.[21] One Chinese expert, Ding Xianfeng, argues that China is well-placed to dominate a digital era that will require trillions of chips, "because China can master this type of chips and sensors, from models, IoT terminals, edge services to cloud computing; China can do all of them." This is an exaggeration; China cannot master all of these different designs now or for the foreseeable future, but it would like to be able to do so.

China's ambitious goal is to create national champions in each semiconductor market segment. At the low end of the market, they have had considerable success. China now supplies more than half of the world microelectronics and hopes to build on this to create similar success in memory, CPU, and AI chips. But China has had embarrassing failures in its efforts to make logic chips. Memory chips are less complex and less expensive to manufacture. There is a huge global market for them that China, building on its strong microelectronics sector, hopes to use as a stepping stone to more sophisticated products.[22] Memory chips will likely be the first major market sector that Chinese semiconductor policy will disrupt.[23]

Chinese firms are becoming competitive in memory chips but face difficulties in manufacturing CPUs or other specialized chips that are globally competitive in price and performance.[24] China still relies on U.S. suppliers for high-end products. Making advanced semiconductors requires more than sophisticated production machinery and advanced designed. It requires "know-how," knowledge and skills built up with years of experience. Even if China gains access to advanced manufacturing equipment, there is still a need for know-how when it comes to making high quality chips with consistent performance at a competitive price. Most Chinese firms still lack this know-how, and the effort to acquire it explains why China's semiconductor strategy turned a few years ago to efforts to buy entire Western firms outright to gain access to the best practices, which are developed

21. Dan Tracy and Clark Tseng, "China's Fab Investment May Extend Record Streak for Wager Fab Equipment," SEMI, January 3, 2018, http://www.semi.org/en/china-fab-investment-may-extend-record-streak-wafer-fab-equipment.
22. Eileen Hannigan ed., *McKinsey on Semiconductors* (New York: McKinsey & Company, Number 6, 2017), https://www.mckinsey.com/~/media/McKinsey/Industries/Semiconductors/Our%20Insights/McKinsey%20on%20Semiconductors%20Issue%206%20%20Spring%202017/McK%20on%20Semiconductors_Issue%206_2017.ashx
23. Gina Roos, "Three Chinese Companies to Start Memory IC Production in 2018," EPSNews, April 26, 2018, https://epsnews.com/2018/04/26/three-chinese-companies-to-start-memory-ic-production-in-2018/.
24. Mark Lapedus, "Will China Succeed In Memory," Semiconductor Engineering, February 9, 2018, https://semiengineering.com/will-china-succeed-in-memory/.

through a blend of experience and expertise over many years. Western regulatory measures, such as the Committee on Foreign Investment in the United States (CFIUS), were successful in blunting these Chinese efforts, and the recent Foreign Investment Risk Review Modernization Act of 2018 (FIRRMA) legislation only strengthens this.

For many years, one of the objectives for U.S export controls was to restrict Chinese access to advanced production equipment. This turned out not to be the chokepoint. Equipment producers wanted to sell to China, Western companies wanted to locate plants in China, and there was a flourishing market in secondhand equipment. The chief difficulty for Chinese firms was not access to equipment but their lack of experience and know-how in making chips. This continues to be a problem for Chinese companies.

For example, while most chips have their programs and instructions "burned" into the silicon, Field Programmable Gate Arrays (FGPA) chips are programmable. China cannot make FPGA.

China attempted to jump-start its FGPA capability by attempting to purchase Lattice, an American firm, but this was denied by the CFIUS in September 2017. Chinese companies, with government support, hope to develop an indigenous capability to supply entry-level programmable chips. China's Integrated Circuit Industry Investment Fund has said it will invest in FGPA manufacturing, but China is still only a minor producer. Wei Shaojun, chairman of China Semiconductor Industry Association's IC Design Branch, said that in FGPA, as well as CPUs and Digital Signal Processors (DSPs), China's technology gap means it, "still does not have the strength to compete with the major international players."[25]

China's Semiconductor Market

China is the world's largest consumer of semiconductors, accounting for about 60 percent of the global demand. This reflects the large Chinese domestic market and, more importantly, China's role of assembler of the world's technology: using imported chips, China assembled 90 percent of the world computers and 70 percent of cellphones in 2011.[26] Most of these devices are re-exported, and China's share of the revenue from sales can be small, something that troubles the Chinese and incentivizes them to "move up the value chain," the processes by which a company adds market value to a good or service. This move will require China to develop indigenous intellectual property for high-tech products that are free from foreign licensing fees.

China plans to attain independence in semiconductor production. It is years if not decades away from achieving this goal despite massive investments, and the goal itself may not be attainable as the industry becomes more globally interdependent. Today, roughly 16 percent of semiconductors used in China are produced in-country. China aims to produce 40 percent of the semiconductors used in China by 2020 and 70 percent by 2025. Some Asian industry observers expect China to achieve this because of government support and heavy domestic demand for chips. The goals behind the subsidization of both indigenous efforts and foreign investments is Beijing's effort to end

25. Yorbe Zhang, "Heavy live coverage! Professor Wei Shaojun 2018 ICCAD speech compete PPT," EET China, November 16, 2011, https://www.eet-china.com/news/201711160900.html.
26. Matt Schiavenza, "China's Dominance in Manufacturing—In One Chart," *The Atlantic*, August 5, 2013, https://www.theatlantic.com/china/archive/2013/08/chinas-dominance-in-manufacturing-in-one-chart/278366/.

"foreign dependency" for semiconductors and move Chinese companies to a dominant global position.

Many of the chips imported by Chinese firms are re-exported from China in other products.[27] Western chip companies have in turn located facilities in China to be close to their customers. China remains a net importer of technology, with only a 14 percent share of global semiconductor production. It is dependent on foreign suppliers for the most advanced chips. Leadership in semiconductor production and ending the reliance on foreign suppliers are the goals of Chinese policy, which are supported by more than $58 billion in different kinds of central government semiconductor investment funds and buttressed by pledges of another $60 billion in 30 additional semiconductor funds created by local governments.[28]

China is only the most recent entrant into the semiconductor industry. The industry was reshaped by the entry of Japan in the 1980s and again by the entry of Taiwan and Korea in the 1990s. While Japan's industry is no longer as powerful as it once was, both Taiwan and Korea are important centers of chip production. The Chinese government hopes that its semiconductor industry will follow a similar path, and Korea and Taiwan are the most likely to suffer as China expands into chip fabrication. If market forces were to predominate, China (or companies and fabs in China) would become part of an interdependent semiconductor manufacturing network centered on the Pacific Rim, but this would not satisfy Beijing's objectives.

The problem with this scenario lies with the techniques China uses to speed its development and attain advantage in semiconductors production, primarily theft of technology, the return of Chinese workers from U.S. firms, and forced technology transfer. There is concern that if China achieved a dominant position in semiconductors, it might attempt to squeeze foreign competitors out of the market or use its lead as a coercive tool by denying or limiting sales. While the efforts of Japan, Korea, and Taiwan raised competitiveness and trade concerns in the United States, they did not raise strategic or military concerns. These countries are partners. China is not.

China's State Council's 2014 "National Integrated Circuit Industry Development Guidelines" set the goal of becoming a global leader in all segments of the semiconductor industry by 2030. The 2015 "Made in China 2025" reiterated these goals. State planning is a remnant of a Soviet-style economic model, and China routinely cranks out economic plans. But what counts is not the plan but the money.

In May 2018, China announced a new fund with $47 billion to improve its semiconductor industry—the government-backed China Integrated Circuit Industry Investment Fund—amid hopes to improve China's ability to design and manufacture advanced microprocessors and GPUs. The China National Integrated Circuit Industry Investment Fund was allocated $22 billion in 2014 from government sources. Another government-

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27. Edward White, "China seeks semiconductor security in wake of ZTE ban," *Financial Times*, June 18, 2018, https://www.ft.com/content/a1a5f0fa-63f7-11e8-90c2-9563a0613e56.
28. Bob Davis and Eva Dou, "China's Next Target: U.S. Microchip Hegemony," *Wall Street Journal*, July 27, 2017, https://www.wsj.com/articles/chinas-next-target-u-s-microchip-hegemony-1501168303?mod=article_inline; Ajit Manoche, "The Rebirth of the Semiconductor Industry," SEMI, September 4, 2018, http://blog.semi.org/technology-trends/the-rebirth-of-the-semiconductor-industry.

backed fund, China's Tsinghua Unigroup Ltd., tried to invest $47 billion over five years to acquire Western companies but was largely blocked by U.S. regulators.

These central government funds are accompanied by local government investments, such as the Chongqing Municipal government's announcement of a $7 billion fund in September 2018. The total planned investment is $118 billion (noting that government spending in China can suffer from politicization and corruption that can reduce the return on investment). For reference, leading Western firms also invest billions annually in R&D—Intel invested over $13 billion while Samsung and Qualcomm invested over $3 billion each.[29]

The history of Huawei, a leading telecommunications company, is suggestive for China's larger technology strategy. China launched Huawei using a combination of industrial espionage against Western telecom firms, state-directed investment, and years of heavy subsidies. This support helped Huawei become one of the leading telecommunications companies in the world, with excellent products and research. It still benefits from access to low-cost credit from the Chinese state that it can use to subsidize foreign customers. Foreign telecom firms have come under sustained pressure as a result. Telecom poses a more immediate security threat than semiconductors, since knowledge and access to telecommunications infrastructure can provide significant intelligence advantage.

Huawei makes first-rate products and offers them at a substantial discount, but the lack of transparency makes this a source of concern. Huawei grew much faster than is normal in this industry, and most research attributes this to heavy subsidies that were not WTO-compliant and to theft of IP (Huawei itself accepted these charges in cases brought by Cisco and Motorola). Huawei is both a precedent and an indicator of what a Chinese semiconductor industry with close links to the Chinese state would mean for the world.

This kind of subsidized Chinese effort is not subject to market forces that would lead unprofitable Chinese companies to exit the industry. State support, from both Beijing and local governments, means that companies can continue to operate even when this does not make economic sense, inflicting damage on both the Chinese economy and the economies of other nations. Han Yinhe of the Chinese Academy of Sciences says that this has created "chaotic competition." Political signals from Beijing have replaced price signals from markets to guide Chinese semiconductor investment. Even Chinese officials worry about overcapacity, and Beijing is attempting to use its central fund to consolidate smaller, unprofitable Chinese chip companies into a few large firms. But in the near term, overcapacity will damage the global semiconductor industry by putting pressure on all firms.[30]

We can demonstrate this using hypothetical numbers. Let's say that there is global demand for 1 billion semiconductors a year, and that 10 companies supply these, each

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29. Yoko Kubota, "China Plans $47 Billion Fund to Boost Its Semiconductor Industry," *Wall Street Journal*, May 6, 2018, https://www.wsj.com/articles/china-plans-47-billion-fund-to-boost-its-semiconductor-industry-1525434907; Li Tao, "How China's 'Big Fund' is helping the country catch up in the global semiconductor race," *South China Morning Post,* May 10, 2018, https://www.scmp.com/tech/enterprises/article/2145422/how-chinas-big-fund-helping-country-catch-global-semiconductor-race.
30. Eva Dou, "China-Backed Fund Plays Big Role in Country's Chip Push," *Wall Street Journal*, July 31, 2017, https://www.wsj.com/articles/china-backed-fund-plays-big-role-in-countrys-chip-push-1501493401?mod=article_inline.

with 10 percent of the market. China then uses subsidies to create 2 more companies. Now there are 12 companies and the market share of each falls to roughly 8 percent. This puts pressure on the existing companies and some will go out of business. Others will look to cut costs to survive and one likely cut will be in research and development. This means that the overall rate of spending on R&D will fall and innovation will slow, unless you assume that the new Chinese companies will conduct R&D at the same level, which China does not yet have the R&D capability to do.

No one can object to the growth and modernization of the Chinese economy; the problem lies with the means the Chinese government uses to achieve this. If China was a market economy and competed fairly in the global semiconductors industry, the entry of new Chinese competitors would be unobjectionable. But China uses non-market techniques to help its companies and put foreign competitors at a disadvantage. In addition to subsidies, these include efforts at forced technology transfer, IP theft, espionage, and regulatory pressure over patents or anti-trust enforcements that Western companies are by themselves ill-positioned to resist. The use of these techniques is a problem that goes well beyond semiconductors (and one the themes of this series of reports is the market-distorting effects of Chinese industrial policy).

Party officials have not hesitated to ignore international norms for trade and intellectual property in their quest for China's growth. The state plays a much larger and more directive role in the Chinese economy. There are real questions about the extent to which the competitive success of Chinese companies is due to state aid rather than to real competitive advantage. China's use of non-tariff barriers to trade and subsidies (along with economic espionage) have become a major trade issue between China and its partners.

"Learning the Superior Techniques of the Barbarians."[31]

This is not an easy market to break into, something that has hampered China's previous efforts to build an indigenous industry. China had national policies for the creation of a domestic semiconductor industry as early as the "Four Modernizations" development program of the 1970s. China has subsidized both indigenous efforts and foreign investors in its effort to end "foreign dependency" for semiconductors. Security is, as with other IT products, a leading concern.

When Deng Xiaoping inherited the Chinese state, he was confronted by its backwardness and poverty, a legacy of Maoist turmoil and ideology. Deng sought to remedy this by opening China's market to foreign investors (and foreign direct investment is one of the best mechanisms for technology transfer) by investing heavily in STEM and by initiating a campaign to acquire technology licitly or illicitly. This espionage campaign was expanded and given unprecedented scope and access by the creation of the global internet and remains a central element of Chinese modernization to this day.

Beginning with Deng, and in reaction to U.S. and European R&D programs, China has launched a number of technology investment and STEM programs for reasons of national prestige, economic competitiveness, and national security. Between 1995

31. Wei Yuan, a nineteenth century reformer; The Asia Society, "Humiliation: Wei Yuan 1794-1857," Wealth and Power, http://sites.asiasociety.org/chinawealthpower/chapters/wei-yuan/.

and 2002, China doubled the percentage of its GDP invested in R&D from 0.6 percent to 1.2 percent. R&D spending reached 2.1 percent of GDP in 2017, and China's GDP is now significantly larger. China says that it intends to double the proportion of science spending devoted to basic research to about 20 percent of its science budget in the next 10 years.

These programs are a source of human capital, producing engineers and scientists but not yet world class products, except in a few fields. The ultimate goal is not only to build a strong economy but also to develop the industrial base needed to build high-tech weapons and reduce reliance on suspect foreign products.[32] Thirty-two years after the first program was announced, China has succeeded in some of these goals, but it is still reliant on Western technology.

The acquisition of Western IP and technology was often a condition of access to the China market. Western firms report that technology transfer concessions are a part of every negotiation with the Chinese. These efforts were buttressed by long-running state espionage programs targeting Western firms and research centers. This technological espionage has carried over into cyberspace, as the Chinese discovered that the internet gave them unparalleled access to poorly secured Western networks. The Chinese were often unable to fully exploit the stolen technology, but as their own skill base improves, the ability to take advantage of the fruits of espionage has increased.

In the 1990s, the United States allowed companies to use Chinese government space launch services to put commercial satellites into orbit, and when a launch failed, the Chinese would collect the pieces of the wrecked satellite to return to the company. In some instances, it was clear that the Chinese first took any semiconductor they found for close examination in the hopes of reverse engineering it. When a chip was finally returned, there were often indications that the semiconductors had been sawn in half or x-rayed in an effort to gain insight into design and manufacturing. These efforts while not fruitful (Chinese efforts to reverse engineer American semiconductors were slowed, if not stymied, by the complexity of the devices), were part of a larger campaign of cyber espionage involving the recruitment of agents in Western companies, forced technology transfer, forced partnership with Chinese companies, and forced relocation of facilities in China as a requirement of doing business there.

While China had been investing in semiconductor manufacturing (and related science and technology education and research for decades), growth in China's semiconductor industry is the product of two related trends. First, the Chinese government created incentives for companies to locate in China and removed obstacles to foreign participation in domestic semiconductor production. Second, Taiwanese investors and semiconductor executives moved manufacturing operations to China, starting with the more basic ones to take advantage of the cost differential and subsidies. Other foreign semiconductor manufacturers from Japan and the United States followed suit, but the Taiwanese influx provided the initial foundation for China's semiconductor industry.

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32. Ministry of Science and Technology of the People's Republic of China, "National-High-tech R&D Program (863 Program)," January 2012, http://www.most.gov.cn/eng/programmes1/.

The continued reliance on foreign involvement is now complicated by increased regulatory scrutiny in Western countries and by regulatory obstacles to technology transfer. Despite Western restrictions on technology transfer, there are still three different avenues that China can use to acquire semiconductor skills. The first is through transfer from Taiwan. Taiwanese semiconductor companies moved into China in the early 2000s to take advantage of Chinese-government subsidies and lower labor costs. Improvements in China's semiconductor capabilities reflect this Taiwanese transfer of skills, now reinforced by the Chinese government's efforts to recruit individual Taiwanese with semiconductor industry skills.[33]

The second is by taking advantage of "fabless" semiconductor production. There are already several hundred Chinese chip design houses, and some of the Chinese IT giants, like Alibaba, use fabless solutions for AI chips. It is interesting that the market solution is to use fabless chip production while the state-centric solution is to build fabs, a much more difficult task and another suggestion that government planning is inefficient.

The third approach is to build an indigenous industry through espionage and IP theft. The damage from this depends on what is being stolen. If China steals chip making technology, it will still face the know-how hurdle. If it concentrates on stealing chip designs which it can then copy and contract out for manufacturing, it may make faster progress.

Another Round of Massive Investment

The current effort under Xi Jinping to end dependence on foreign chips is China's fifth attempt. China has spent billions of dollars in the preceding decades to create a domestic semiconductor industry, but with little success.

Beijing attempted to overcome the know-how gap by trying to purchase Western semiconductor companies outright, acquiring not only machines and IP, but the people who knew how to use them. With support from the central government's China Integrated Circuit Industry Investment Fund (sometimes called the "Big Fund," created to "promote leapfrog development of China's integrated circuit industry"),[34] state-backed firms attempted to acquire American chipmakers, such as Lattice, Micron Technology, and Western Digital Corporation. In total, Chinese investors and firms offered more than $30 billion in bids for U.S. and European semiconductor companies between 2015 and 2017.[35] This heavy-handed effort, complicated by China's predatory practices in other sectors, raised concerns in many countries. Governments in Europe and Asia joined the United States in blocking these Chinese acquisition efforts.[36]

One important effect of the massive state funding dedicated to semiconductors is to change the incentive structure for Chinese entrepreneurs and businesses, making it more

33. Kathrin Hill, "US fears attempts by Chinese chipmakers to grab top talent," *Financial Times,* November 2, 2018, https://www.ft.com/content/eb145d60-dda7-11e8-9f04-38d397e6661c.
34. "Establishment of China Integrated Circuit Industry Investment Fund (ICF) and Its Management Company," Chinese Development Bank Capital, http://www.cdb capital.com/GKJR/informationen/17102015224017.
35. Bob Davis and Eva Dou, "China's Next Target: U.S. Microchip Hegemony," *Wall Street Journal*, July 27, 2017, https://www.wsj.com/articles/chinas-next-target-u-s-microchip-hegemony-1501168303.
36. Bob Davis and Eva Dou, "China Faces Foe in Tokyo, Seoul and Beyond on Semiconductors," Real Time Economics (blog), *Wall Street Journal*, July 27, 2017, https://blogs.wsj.com/economics/2017/07/27/china-faces-foes-in-tokyo-seoul-and-beyond-on-semiconductors/?mod=article_inline.

attractive for them to enter the industry.[37] Chinese firms have both government and commercial incentives to enter the chip market, particularly through the multi-billion-dollar gaming industry and the pursuit of AI. China's fascination with cryptocurrency has led firms to explore making their own chips geared specifically to mining. Others are attempting to build AI specific chips, such as Rokid's Kamino18 chip, designed by a team led by a Chinese national who was the former research director from Samsung Semiconductor China. The blend of political inducements and commercial motives makes China's semiconductor push a powerful challenge.

While the preference among Chinese policymakers is to build an indigenous IT supply chain, on the theory that this best eliminates national security risk, a more sophisticated approach would seek to make China the dominant partner in the global market. China still needs access to Western technology and know-how, and the dominant partner approach better fits the global nature of distributed innovation with foreign partners. Partnerships between foreign firms and a commercially and technologically dominant China is also a better fit for the tributary trade precedent that guided China in the past. This is most likely the direction China will be forced to move, as an indigenous industry—even when supported by espionage, subsidies, and foreign education—will remain second-best in a globally integrated innovation system.

China as an Innovator

The long-standing debate about whether China could become an innovation power appears to be over (with two significant caveats).[38] The first caveat is that Chinese innovation is still limited and constrained by the country's relative technological backwardness in most sectors. China has moved an immense distance from the impoverished, agrarian economy left by Mao, but it still lacks the depth of scientific and technology knowledge found in other countries, and efforts to insert the CCP and government control in innovation and entrepreneurship slow progress.[39] An increasing role for the Chinese government (and the CCP) in directing the economy may damage innovation.

The second caveat is that is that Chinese innovation blossomed in a period of relative political openness. Advances in China's IT sector accelerated when Beijing reduced its directive role, particularly after a 2003 State Council decision to "separate the government functions from those of the enterprise."[40] Now that openness is shrinking under Xi Jinping, accompanied by greater state economic direction and political tightening, it is possible

37. Sophy Yang, "Chinese Electronics Firm Gree Sets Up $1B To Expand To Semiconductor Sector," China Money Network, August 22, 2018, https://www.chinamoneynetwork.com/2018/08/22/chinese-electronics-firm-gree-sets-up-1b-unit-to-expand-to-semiconductor-sector.
38. Best explained in CSIS's "The Fat Tech Dragon: Benchmarking China's Innovation Drive," August 2017: "China's innovation performance has gradually improved over the last decade along a number of indicators, separating China from other major emerging economies. Yet China still has a substantial distance to travel." See also Susan Kelley, "China cracks top 20 in Global Innovation Index," Phys.org, July 10, 2018, https://phys.org/news/2018-07-china-global-index.html.
39. Yi Wen, "China's Rapid Rise: From Backward Agrarian Society to Industrial Power in Just 35 Years," Federal Reserve Bank of St. Louis, April 2016, https://www.stlouisfed.org/publications/regional-economist/april-2016/chinas-rapid-rise-from-backward-agrarian-society-to-industrial-powerhouse-in-just-35-years.
40. "China State-owned Assets Management System Reform Entering New Stage," State-owned Assets Supervision and Administration Commission of the State Council, May 22, 2013, http://www.china.org.cn/e-news/news03-0522.htm.

that the trend of increasing Chinese innovation will reverse itself, a concern that some Chinese researchers share.[41]

The metrics to watch here are the outflow of Chinese entrepreneurial and research talent and money from an increasingly controlling state. One indicator is that in several high-profile cases, employees of Western firms who have been hired away from Chinese companies have left China after a year or two. Chinese "Thousand Talents" program, which offers a cash reward and access to funding to returnees and foreign experts, can best be described as good at recruitment, bad at retention.[42]

Traditional innovation metrics (number of patents, PhDs, R&D spending, or scientific publications) are less useful for China because of duplication, inaccurate comparisons, and, in some instance, outright fraud in Chinese metrics.[43] For semiconductors, the best metrics remain how dependent China is on imported chips, and this dependence continues to grow. Despite claims in the government-controlled media of China approaching technological parity to the West (too often taken at face value in Western media), more sober assessments from Chinese scholars suggest that while China is strong in some research areas there is still a significant lag in the ability to create new technologies that can be reduced only by access to Western commercial and educational resources.[44]

Improved Chinese innovation capabilities change the risk landscape for espionage and IP theft. The risk of IP theft and illicit tech transfer was lower when the Chinese economy was more backward. The Chinese often could not absorb and use the technology that they had stolen. This has changed as China modernized. Decades of investment in education and research, buttressed by foreign direct investment (FDI)—one of the best vehicles for technology transfer—heavy government funding for strategic technologies, and rampant commercial espionage have built a strong innovative capability in China.

Market Versus State

Both China and the United States have advantages and disadvantages in this technology contest, and while it is common to focus on quantitative aspects of the contest, these are not always the best indicators. This is also a contest of ideas on governance and investment and the balance between market forces and political direction. The increasingly multinational nature of research and innovation complicates any competition for technological leadership and will create forces that both nations will find difficult to control. In this pursuit, a globally-oriented U.S. industry may have an advantage over a nationally-focused China.

Mao believed that revolutionary fervor could overcome superior technology, but when Deng Xiaoping took over, he found that China lagged so far behind in technology that the

41. Research by Zhang Weiying, a Beijing University advocate of free markets for China, suggests that regions with higher degrees of marketization and fewer SOEs have more patent applications, R&D intensity, and new commercial products, while having a higher numbers of government entities, public sector employment, and state holding companies in a region correlate negatively with patent applications.
42. Yojana Sharma, "China's Effort to Recruit Top Academic Talent Faces Hurdles," The Chronicle of Higher Education, May 28, 2013, https://www.chronicle.com/article/Chinas-Effort-To-Recruit-Top/139485.
43. Amy Qin, "Fraud Scandals Sap China's Dream of Becoming a Science Superpower," *New York Times*, October 13, 2017, https://www.nytimes.com/2017/10/13/world/asia/china-science-fraud-scandals.html.
44. Yuan Yang and Lucy Hornby, "China raises alarm over its dependency on imported chips," *Financial Times,* July 18, 2018, https://www.ft.com/content/410306d8-8ae0-11e8-bf9e-8771d5404543.

country was at serious risk militarily and economically. Deng opened China's economy after Mao but ultimately crushed any movement toward a parallel political opening. The old Maoist themes of resolutely countering aggression from an implacably hostile West still echo in policy, but they are now accompanied by a self-confidence and assertiveness that amplifies their effects. There is a desire to rearrange global rules and institutions to better serve China's interests. China endorses the rule of law but with Chinese characteristics, which means that the CCP's leaders are the ultimate arbiters of any decision. There is a still degree of both insularity and hostility in the worldview of these leaders.

Chinese companies have been successful in producing low-value, labor-intensive goods, making China the largest producer of manufactured goods in the world, but the last few Five-Year Plans, a model for economic control adopted from the Soviet Union, have set the goal of moving "up the value chain" from assembling final products from imported components to building advanced technology in China itself.[45] This move is important for commercial, technological, and political reasons. A larger share of revenue goes to companies that occupy the high end of value creation. A higher position on the value chain requires both business and technological expertise. Being higher on the value chain shows China has achieved the Party's political goal of becoming a modern economy. One question rarely asked in China is whether this government direction is necessary? Would Chinese companies have been better incentivized to move up the value chain if more efficient market processes guided investment and competition?

Centrally-directed economies are less efficient in the allocation of resources. Government policy supplants market signals on how best to invest and lack the self-correcting mechanisms provided by market forces—government tend to keep failing companies afloat long after it stops making economic sense. Both Korea and Japan saw this drive the misallocation of capital. In the short term, these strategies produced rapid industrialization, but in the last few years they have worked to slow economic growth. Easy access to credit allowed less efficient firms to survive, draining resources from more productive activities. The question for China's IT sector is how many of the new Chinese firms will still be operating a decade from now.

In China's IT industry, the risk of overinvestment springs from a number of sources. National policy has made the creation of a Chinese IT industry a priority, with the result that ministries, and provincial or local governments invest more in this sector than they otherwise would. Government policy has also made credit easier to obtain for such investments, especially for enterprises where the state has an ownership role. Easy credit is a key ingredient for overinvestment, and a boom mentality hobbled previous Chinese efforts to build a semiconductor industry.

There is considerable risk of ill-advised investment. The semiconductor industry has a history of multi-year investment cycles. These cycles begin with recovery from oversupply and low prices as demand for semiconductors increases, move to full utilization of existing production capacity to meet the increased demand, and then see investment in new capacity as demand increases (and it can take two to three years while the new fabs are

45. Tom Hancock, "China's relentless export machine moves up the value chain," *Financial Times*, September 23, 2018, https://www.ft.com/content/cdc53aee-bc2e-11e8-94b2-17176fbf93f5.

built). Finally, as the new production capacity comes online, the cycle begins again with a return to oversupply and falling prices. The recovery and boom phases are usually longer than the bust phase. Many analysts fear that the oversupply phase may come earlier than normal because of the Chinese government's investments, despite growing global demand.

Investment decisions in China are still principally shaped by government policy. Provincial and local governments provide funds or direct state-controlled financial institutions to make loans. There is a strong and perhaps increasing element of central planning. Chinese government investments have not always performed well in the past (demonstrated by the immense "debt-overhang" at the provincial and municipal level). These factors suggest that the Chinese IT sector may have unappreciated vulnerabilities that will slow its performance.

The Perils of Techno-Triumphalism

One dilemma that distorts the entire debate is the Chinese government's propensity to exaggerate its technological and scientific prowess. If the United States has suffered from a degree of technological hubris, this is another area where China appears to be copying the United States. This exaggeration has become more pronounced under President Xi Jinping, part of the triumphalist narrative about China's return to the center of the world stage (under party leadership) and how it is China's moment to claim global dominance. In reality the story is more nuanced and uneven, particularly for advanced technology, with China leading in a few areas (such as biotechnology, where Chinese firms face fewer regulatory hurdles) and lagging in most others.

The issue is complicated by political trends in China. Incipient discontent with Xi can be expressed as skepticism over techno-triumphalism. A recent Ministry of Industry and Information Technology (MIIT) survey showed that China is far from the lead in most key technology areas.[46] The consequences for ZTE when the U.S. government cut off access to U.S. technology came as a shock to the Chinese (and reinforced their belief that they need indigenous sources of supply). A few respected Chinese scholars have taken a nuanced and skeptical view of China's progress toward leadership.[47] CCP may well have instructed the media to "cool it" about China's technological leadership and to downplay "Made in China 2025" (a strategic economic plan issued by Beijing), which has become something of a hobgoblin for Americans.

"China 2025" has become a catchphrase for the CCP's aggressive industry policy, but we should not take yet another report by Chinese planners too seriously. More important dates are 2030, when the IMF estimates that China's GDP could *ceteris paribus* overtake the United States, and 2049, the hundredth anniversary of the party's seizure of power. Changing Chinese behavior will be difficult but not impossible if the United States and its allies take a consistent long-term approach. But in the near term, policies should focus on blunting Chinese acquisitions of technology and adopting measures to reinforce U.S. technological strength, such as investing more in basic science and government research and taking a

46. He Huifeng, "Beijing did a tech reality check on its industrial champions. The results were not amazing," *South China Morning Post,* July 18, 2018, https://www.scmp.com/news/china/economy/article/2155862/beijing-did-tech-reality-check-its-industrial-champions-results.
47. Sydney Leng, "China must stop fooling itself it is a world leader in science and technology, magazine editor says," *South China Morning Post,* June 26, 2018, https://www.scmp.com/news/china/society/article/2152617/china-must-stop-fooling-itself-it-world-leader-science-and.

more assertive approach to issues involving foreign regulations of IP and competitiveness, which can sometimes be a stalking horse for unfair competitive advantage.

We can establish where China is now by looking at what it imports and exports. This shows that China is still dependent on the West for semiconductors and semiconductor manufacturing equipment. It is harder to predict where China will be in 10 years, given its massive investments. With each iteration of its pursuit of technological leadership in semiconductors (and other areas), China improves its performance, but each iteration to date has fallen short of technological independence. The Party's intent is clear, and there has been real progress, but China is years away from parity.

A related metric is to look at what technologies China attempts to acquire illicitly. This metric is not ideal since the scope of Chinese illicit acquisition activity encompasses a broad range of technologies, advanced and not so advanced, as it is driven by both strategic and commercial imperatives. But if we focus on state-directed programs, there is no advanced technology area where China does not continue to pursue illicit acquisitions from foreign sources. The only exceptions might be in biotechnology (China invested over a billion dollars in U.S. biotech startups in Q1 of 2018) and quantum communications.[48]

China is not a market economy (although it may be a "market economy with socialist characteristics"). The central government plays a much larger and more directive role in the Chinese economy. This may have helped development, but it is now an obstacle to further growth. Given the linkage in China between politics and economic decision-making, the temptation for CCP leadership is to expand governmental involvement in the economy and in investment decisions. State capitalism and corruption make finding the balance for the role of government difficult. If the United States has gone too far in restricting the role of government, China has gone too far in putting government in charge of decisions best left to markets.

China's use of non-tariff barriers to trade and subsidies (along with economic espionage)—all state-driven economic actions—are becoming a major trade issue between China and its partners. The Chinese assumption that it can escape interdependence runs counter to larger trends in innovation and to the policies previously used by China to achieve modernization.

China also faces the problem that its pursuit of indigenous innovation runs counter to the trend that globally integrated supply chains are the most efficient, both in production and in innovation. It is better to think of a global IT innovation ecosystem stretching from the Pacific Rim to Israel and even Europe, centered on Silicon Valley. Chinese companies are served best by integrating with this ecosystem rather than repelling Western investment through restrictive laws and practices in IP protection, join ventures, and market access that increasingly discourage Western partners.

This does not reduce the risk of the potential market distortions that China's aggressive industrial policy might create, and it may suggest a renewed Chinese effort at illicit

48. Rebecca Spalding and Emma Ockerman, "Chinese Money Floods U.S. Biotech as Beijing Chases New Cures," *Bloomberg,* April 18, 2018, https://www.bloomberg.com/news/articles/2018-04-18/chinese-money-floods-u-s-biotech-as-beijing-chases-new-cures.

technology transfer. Nor does it address questions about the status of America's own innovation capabilities, where the rate of change is largely independent of China.

For semiconductors, China's progress is largely the result of partnerships with Western companies, particularly if that measure includes Taiwan. The future growth of IC production in China depends more on whether foreign companies continue to locate fabs in China, which transfers skills to Chinese workers, than on the success of indigenous Chinese IC producers.[49]

Seeking Security in the IT Supply Chain

Security in semiconductors and other IT products is a primary concern for Beijing. Chinese officials worry that relying on foreign-made (or -designed chips) damages the security of information and makes infrastructure vulnerable to foreign access and interference. Intelligence agencies are resourceful, and the foreign production of hardware provides an opportunity for them to gain intelligence advantage or to disrupt critical infrastructure. A potential opponent could take advantage of the manufacturing process to intentionally introduce malicious flaws. Also, the effort to build an indigenous semiconductor industry is part of the larger goal of overtaking the United States.

China has long suspected that Western semiconductors contain "backdoors" or intentional vulnerabilities that can be exploited for intelligence and military purposes. As early as 2004, an article in *People's Daily* reported that "in peacetime, the United States sells virus-carrying chips as ordinary commodities to the key departments of other countries. When needed in war-time, the United States can remote control and activate the virus at any time, making ineffective or paralyzing the enemy's commanding and weaponry systems. If one depends completely on imported chips, one will likely suffer heavy losses on future battlefronts."[50] The 2013 Snowden revelations seems to confirm all of China's worst fears about supply chain security.

In 2016, Xi Jinping, in a widely publicized speech on cybersecurity, said "the fact that core technology is controlled by others is our greatest hidden danger . . . ."[51] His remarks have many precedents since the opening to the West. Wu Dexiang, a member of the National People's Congress and the former director of the China Microelectronics Centre Study Committee, said, "We cannot be reliant on foreign chips. Our microchips are all imported. We do not make our own chips. Our whole industry is built on sand. These chips are like the heart of a person. If the source of supply is cut off, our heart will stop beating." Echoing this long-held official view, Vice Premier Ma Kai said at the 2018 National People's Congress, "We cannot be reliant on foreign chips."

These Chinese fears have no basis in reality, and the pursuit of indigenous technology reflects a misunderstanding of network security, but these statements are a strong indicator of China's own intentions should it establish a dominant position in

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49. "Foreign IC companies to represent 70% of China's IC production in 2017," Solid State Technology, https://electroiq.com/2013/07/foreign-ic-companies-to-represent-70-of-china-s-ic-production-in-2017/.
50. "China Must Accelerate Development of the Important Chip Industry," *People's Daily*, April 24, 2004, http://english.peopledaily.com.cn/200404/22/eng20040422_141201.shtml.
51. Xi Jinping, "Speech at the Work Conference for Cybersecurity and Informatization," (speech, Beijing, April 2016).

semiconductor production. Whether the Chinese have the technical ability to put such a supply chain infection strategy in effect (the chief challenge being that the chip has to perform its functions flawlessly, something that can be difficult enough without tampering with design or production) is open to question, and recent stories about supply chain infections at SuperMicro were wrong.[52] Frankly, China's networks and devices, often based on pirated or outdated software, are so vulnerable that there is little incentive to use high-risk, high-cost supply chain attacks, and one result of the insistence on the use of indigenous products by China has been, counterintuitively, to reduce security, as many of these Chinese products are often not as good as what is available on the global market.

How Should the United States Respond?

The United States wrestles with similar national security concerns over a reliance on Chinese sources of supply for microelectronics. China's semiconductor effort, if successful, would damage U.S. and Western semiconductor companies and create opportunities for espionage and disruption. A larger issue is that the semiconductor battle is a microcosm of how a newly powerful China will define its relations with the rest of the world. Will China play by the rules or will it continue to cheat? China will be rich and powerful no matter what path it follows, but the latter path leads to global turmoil, what some like Prime Minister Mahathir of Malaysia have called China's "new colonialism" based on the coercive use of China's economic power.[53]

The United States depends on technological superiority to give it an advantage over more numerous opponents. If China is able to erode the U.S. technological lead and close the technological gap, U.S. security will be damaged since China has become an overtly hostile power. We cannot realistically expect to block China's growth and development, so the issues are to accelerate technological innovation within the United States and our allies and to ensure a cooperative security and science relationship with partners around the world. Close attention to the factors that make Silicon Valley a success—research, investment, and immigration—is essential, but the same political predicaments that afflict U.S. policymaking have hampered our ability to do this and, counterproductively, even harmed the American innovation model.

One major disadvantage for the United States is the ideological debate over the role of government and government spending. This began in the 1990s and has led to decades of underinvestment in public goods. The goal of cutting taxes has led to significant and damaging underinvestment in infrastructure and research, harming the competitiveness of American companies and reducing the growth of the U.S. economy. The Chinese government, although hampered by its one ideological constraint, has no reluctance to spend money for decades on strategic goals.

In the 1940s, the United States found a new way to harness government investment in science to create military power and economic wealth. Other countries want their own

52. Kieren McCarthy, "Forgotten that Chinese spy chip story? We haven't – it's still wrong, Super Micro tells SEC," *The Register*, October 22, 2018, https://www.theregister.co.uk/2018/10/22/super_micro_chinese_spy_chip_sec/.
53. Lucy Hornby, "Mahathir Mohamad warns against 'new colonialism' during China visit," *Financial Times,* August 20, 2018, https://www.ft.com/content/7566599e-a443-11e8-8ecf-a7ae1beff35b.

DARPAs and Silicon Valleys. China in particular has tried to copy the United States, and China combines research investment with a mercantilist industrial policy intended to give Chinese companies an advantage over foreign competitors, first in the domestic market and then abroad.[54]

This was acceptable when China was a developing economy, but it is no longer tolerable when it is the second largest economy in the world and a potential military competitor. The United States is unprepared for this competition and is just beginning to shift its strategic focus from counterterrorism and counterinsurgency to great power competition. An easy way to think about this is that the United States spent over a trillion dollars bringing democracy to Afghanistan, while China spent a similar amount on science and technology. That China is not closer to overtaking the United States only reflects the immensity of the gap in wealth and technology between the two countries.

That said, the Chinese are not 10 feet tall, and while their propaganda machine energetically paints their rise as unstoppable, they face many obstacles. For technology and semiconductors, the most important hurdles involve innovation and investment. China's political closing may harm indigenous innovation, but there is more risk in pushing to develop a national system at a time when the most successful developments in technology and science come from a multinational, cross-border innovation system. Nor can China assume that the world will remain compliant in investment and technology transfer in the face of an openly assertive Chinese industrial policy that is now widely perceived to be unfair. China might have been better served by maintaining a Deng-like profile for longer, but perhaps the Party's own calculations of what was needed for its political existence suggested a more assertive posture.

We also need to bear in mind that it is the CCP, and not the Chinese, that is the source of hostility to the United States. Chinese leaders worry about the precedent of the Soviet collapse and under Xi have put in place pervasive surveillance, appeals to Maoism, and heightened nationalism to avoid a similar fate. Economic growth is part of this effort, buttressed by Chinese expectations of resuming their rightful place in the world. Xi needs growth and control for domestic reasons, and this will make it difficult, but not impossible, to restore the formerly close commercial and technological partnership with China. If the ruling party chose another path, it would make it easier to integrate China into the community of nations, but they will not choose a path that risks leading to their own demise.

We have not faced serious competition for three decades. This is not another Cold War. We cannot contain China, nor have we succeeded in deterring it, particularly if the American goal is to stop illicit technology acquisition or mercantilist trade and industrial policies. Neither Cold War science and technology policies or a laissez faire approach to innovation will keep us in the lead. Attempts to rebuild a national supply base run counter to the efficiency provided by a transnational approach to business and research and is unlikely to succeed if the goal is to produce cutting edge products. Of the two countries, the United States is better positioned to take advantage of this multinational

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54. Phred Dvorak and Yasufumi Saito, "Silicon Valley Powered American Tech Dominance—Now It Has a Challenger," *Wall Street Journal*, April 12, 2018, https://www.wsj.com/articles/silicon-valley-long-dominated-start-up-fundingnow-it-has-a-challenger-1523544804.

supply chain. China's only advantage is its willingness to spend, and until recently, it was innately less welcoming of immigrants than the United States. The United States needs new policies that mix supportive federal investments, partnerships with the private sector and academics (including foreign entities), and assertive trade and IP protections internationally if it is to do more than watch China slowly close the technology gap.

The U.S. model for innovation has worked for 70 years. Federal investments in research had remarkable spill-over effects for the economy, creating new products like the jet engine, semiconductors, and the internet. This began to slow in the 1990s because of a series of changes in government spending, the global diffusion of research and technology, and Congressional politics. Competition over innovation has increased significantly, and Americana needs to speed up, not slow down, only some of which were in our control. N Li Xuwu, the head of R&D at a leading Chinese semiconductor firm summed it up as "the advanced countries slow down, and the less-advanced will catch up easily with the exploration of foreign companies, latecomers can take a lot less detours."[55]

The recently passed Foreign Investment Risk Review Modernization Act (FIRRMA) and the accompanying Export Control Act of 2018 codify and strengthen the CFIUS review process and mandate that the United States develop partnerships with other Western nations to coordinate their foreign investment reviews. This coordination is essential as China will go from country to country when seeking acquisitions. Export controls are a more difficult problem, as they need to be modernized and oriented toward promoting American exports in ways that make them less capable of mitigating risk.

China has in the past been able to exploit loopholes in American export control regulations (and its enforcement) to acquire semiconductor technology. In particular, some in the U.S. semiconductor industry believe that technology transfers approved by the Department of Commerce in 2010 boosted Chinese semiconductor abilities. The Export Control Act of 2018 is intended to strengthen export controls and prevent similar incidents, but this will be a difficult task given the Cold War heritage of export control systems and the desire to give trade promotion precedence over national security. These regulatory measures are important, but they need to be accompanied by measures to strengthen the chip industry and to smooth distortions in foreign markets intended to provide competitive advantage. This includes stronger IP protections and enforcement.

When Japanese companies, with government support, began to compete with American semiconductor firms in the 1980s, the United States responded by engaging with Japan on trade and creating SEMATECH (through DARPA), a research consortium with private companies to improve the competitiveness and technological base of American companies. SEMATECH allowed companies to share resources, risks, and costs in pre-competitive research. This response laid the foundations for continued American strength in semiconductors and is precedential for responding to China's semiconductor plans. We don't need another SEMATECH, but we do need a well-funded national response that blends public and private sector action.

55. 新闻分析：中国如何突破"缺芯"困境, Xinhua News Agency, April 19, 2019, http://www.xinhuanet.com/fortune/2018-04/19/c_1122711215.htm.

While there are growing concerns that an economic "iron curtain" will separate the two economies, given the increasing political tensions, the United States should not expect to replicate the Cold War bifurcation between the West and the Soviets. The United States would not benefit from economic warfare with China (nor is there a shred of evidence that China has nefarious plans for a "death by 1000 cuts" for the U.S. economy). A laissez faire approach to China would damage the economic and security interests of the United States and its allies, but so would heavy-handed restrictions. A more nuanced approach that combines existing regulatory tools such as CFIUS and export controls to restrict Chinese access to advanced semiconductors technology in coordination with our allies and combined with continued pressure to amend China's unfair trade practices is essential. Finding ways to expand spending on R&D while significantly increasing the level of and resources for counterintelligence activity against China is similarly important. An abrupt rupture will not serve U.S. interests, but increased vigilance is essential.

A U.S. response will need to engage China to change its behavior while taking steps to strengthen the U.S. semiconductor industry (noting that these steps will be different than the 1980s response).[56] Partially in response to the Chinese efforts, DARPA's Electronics Resurgence Initiative (ERI) and other programs will draw on research and collaboration among companies and academics for work in six research areas. The program has more than a billion dollars in funding intended to accelerate next-generation chip technologies and production to overcome the limits on continued performance growth using current technology.[57] This is a strong start, but the United States will need to invest more (and more consistently) in government research to keep pace with China. One benefit of increased support for basic research is that it, along with increased support for STEM education, can help build the advanced workforce needed to remain technologically competitive.

The U.S. semiconductor industry and national security are closely linked. A decline in one damages the other. Semiconductors are a strategic industry. They are the foundation of modern electronics, from mobile phones and fitness bands to satellites and weapons systems. Semiconductor technology enables advancements in a range of industries, including computing, communications, and robotics, and improvements in the semiconductor industry have delivered significant gains in performance and productivity across the board in the U.S. economy. Semiconductors will be a growth industry, as every IoT device will contain at least one chip and will need some ability to connect wirelessly to internet resources.

One proposed solution that can initially appear tempting is to recreate the "trusted foundries" program previously used by the United States. The problem with trusted foundries is money. A modern semiconductor fab now costs more than $15 billion. There are still a few "trusted" fabs in the United States, operated by National Laboratories in some cases (and until 2014, under contract to IBM), that build specialized semiconductors for sensitive systems such as nuclear weapons, but the United States has been unwilling to foot the bill to modernize these facilities. In most instances, commercial chips

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56. Robert D. Hof, "Business Report: Lessons from Sematech," MIT Technology Review, July 25, 2011, https://www.technologyreview.com/s/424786/lessons-from-sematech/.
57. "DARPA Electronics Resurgence Initiative," Defense Advanced Research Projects Agency, https://www.darpa.mil/work-with-us/electronics-resurgence-initiative.

outperformed those supplied by trusted fabs and were significantly cheaper. The United States would be better served by a combination of policies to support the domestic semiconductor industry, expanding programs to allow the trusted use of fabless processes, and reinforcing the research base needed for semiconductor innovation.[58]

The United States made a strong semiconductor industry a goal for policy in the past, and the response to the risk of Japanese domination of the industry helped spark a renaissance for the American tech sector. But the solutions of the 1980s do not fit a dynamic, globally-distributed market. The most efficient and innovative supply chain for semiconductors and other advanced technology will be multinational. Finding ways to maintain the semiconductor industry's role in national security and identifying ways to protect it will not be easy, but it is essential for continued American leadership in the twenty-first century.

There is no easy solution to dealing with China's semiconductor effort. It is part of the larger economic contest between the United States and China over whether the CCP will follow international trade and investment rules or continue to ignore them when it decides this is in China's interest to do so. Part of China's exploitative trade policy is to squeeze U.S. semiconductors out of the China market while sucking Western semiconductor technology in. There should be no doubt as to which outcome is best for the United States.

58. U.S. Government Accountability Office, *Trusted Defense Microelectronics: Future Access and Capabilities are Uncertain, Statement of Marie A. Mak, Director Acquisition and Sourcing Managing,* GAO-16-185T (Washington, DC: 2015), https://www.gao.gov/assets/680/673401.pdf.

About the Author

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Lewis was the rapporteur for the UN Group of Government Experts on Information Security for the successful 2010, 2013, and 2015 sessions. He has led long-running Track 1.5 discussions on cybersecurity with the China Institutes of Contemporary International Relations. He has served on several Federal Advisory Committees, including as chair of the Committee on Commercial Remote Sensing, and as a member of the Committees on Spectrum Management and International Communications Policy and the State Department's Advisory Committee on International Communications and Information Policy. Lewis has authored numerous publications since coming to CSIS on topics, including innovation, satellites, information technology, globalization, deterrence, and surveillance. He was the director for CSIS's Commission on Cybersecurity for the 44th Presidency and is an internationally recognized expert on cybersecurity. Lewis's current research examines the effect of technology on conflict and how the internet has changed politics. He received his PhD from the University of Chicago.

Appendix: Chinese Semiconductor Planning and Initiatives, 1956-2018

1956 – The Long-term Plan for the Development of Science and Technology for 1956–1967 1956 – 1967 (“年科学技术发展远景规划”)

- China’s first long-term science and technology plan. It is often credited as a visionary blueprint for its nuclear weapons programs and industrialization.
- The plan listed semiconductor technology as one of key electronics projects for national defense among telecommunications and broadcasting systems, R&D of radio electronics, and computer and radio technology for national defense.
- China also announced it will study semiconductor science. The plan led to the creation of semiconductor science majors in five universities in 1957.

1960 – The Institute of Semiconductors (IOS) of the Chinese Academy of Sciences (CAS) was founded in Beijing. Since its founding, IOS has become one of the most important bases for semiconductor research and development in China.

1982 – The State Council established Electronic Computer and Large-Scale IC Leading Group (“电子计算机和大规模集成电路领导小组”) to strengthen the leadership in developing these industries and proposed to improve China’s IC industry during the 6th Five-Year plan.

1983 – The Large-Scale IC Leading Group proposed to fix messy and decentralized development of IC (“治散治乱”). They proposed a strategy of building “2 bases and 1 place” (“南北两个基地和一个点”). “Two bases” referred to one base in the south (Shanghai, Jiangsu, and Zhejiang) and one in the north (Beijing, Tianjin, and Shenyang). “One place” is Xian for the aerospace industry.

1995 – Ministry of Electronics (MIIT now) proposed the “‘95’ IC development strategy” (“‘九五’集成电路发展战略”)

June 2000 – The Notice on Encouraging Software and IC Industry Development from State Council, also known as Document No. 18 (“国务院关于印发鼓励软件产业和集成电路产业发展若干政策的通知”)

- This document elevates IC development to national strategic level.
- This document further encourages the development of the software and IC industries.
- The document expired in 2010 and was exceeded by State Council Document No. 4 as part of the 12th Five Year Plan published in February 2011.

2002 – Document on State Council Office Further Completing Software and IC Industry, or Document No.51 ("国务院办公厅关于进一步完善软件产业和集成电路产业发展政策有关问题的复函 [51号文件]").

February 2006 – Outline of Long and Medium-Term National Scientific and Technological Development Program (2006-2020)

- According to the Outline of Long and Medium-Term National Scientific and Technological Development Program (2006-2020), core electronic equipment, high-end chips, and software are listed as the most prioritized key project, while large-scale IC manufacturing technology is listed as the second most prioritized key project, among 13 key projects.

February 2011 – The Notice on Further Encouraging Software and IC Industry development from State Council Document No. 4 ("国务院关于印发进一步鼓励软件产业和集成电路产业发展若干政策的通知")

- The document included a set of measures to further boost the software and IC industry.
- It signaled an important shift from an emphasis on quantitative growth of production capacity and output to a focus on improving R&D capacities for advanced technology.
- It selectively supported a small group of semiconductor-makers with global market share and the capacity for technology innovation.
- In contrast to Document No. 18, Document No. 4 places greater emphasis on pragmatic choices based on a careful selection of which key bottlenecks and medium-term goals might be achievable with the current set of accumulated capabilities.

April 2012 – The Notice on Corporate Tax Policy for Further Encouraging Software and IC Industry Development from State Administration of Taxation and Ministry of Finance, or Document No.27 ("关于进一步鼓励软件产业和集成电路产业发展企业所得税政策的通知")

- This was a tax cut for IC companies.

February 2012 – 12th Five-Year Plan on IC Industry Development ("集成电路产业十二五发展规划")

June 2014 – National IC Industry Development Outline

- Move from catching up to forging ahead in semiconductors by simultaneously strengthening China's IC design industry and domestic IC foundry services.
- Establish National IC Industry Development Leading Group and National IC Industry Consulting Commission.
- Establish National IC Industry Investment Fund ("Big Fund").
- Reach 350 billion RMB for total sales by 2020.

- Implement taxation policy to crystalize Document No. 4 and Document No. 18.

Local Governments Programs

- July 2014 – (Shandong) “Implementation of Document No. 4 to speed up IC industry development”
- July 2014 – (Gansu) “Gansu Province’s implementation of National Framework for Development of the IC Industry”
- August 2014 – (Anhui) “Accelerating IC industry development”
- August 2014 – (Sichuan) Sichuan worked out IC industry development implementation policies and set up IC industry investment fund.

September 2014 – National IC Investment Fund “Big Fund” (“国家集成电路基金”)

- The first phase of “Big Fund” invests mainly in IC manufacturing.
- The second phase will have a higher investment proportion on IC design.

May 2015 – Made in China 2025

- The plan highlights electronics and semiconductor technology as one of the top 10 focus areas.
- Chinese firms are expected to double their market share to 40 percent by 2020, from 20 percent last year, and to 70 percent by 2025.

March 2016 – 13th Five-Year Plan Outline

- Highlights the need for China to develop strategic emerging industries, including semiconductors.
- Narrows down the scope of support and requirements for IC firm qualification in comparison to 12th Five-Year Plan and use the National IC Investment Fund instead.

May 2016 – Key Software Industries and IC Design under National Plan and Positioning (“四部委关于印发国家规划布局内重点软件和集成电路设计领域的通知”)

August 2016 – 13th Five-Year Plan for National Science and Technology Innovation (“‘十三五’国家科技创新规划”)

November 2016 – 13th Five-Year Plan on Developing National Strategic and Emerging Industries (“‘十三五’国家战略性新兴产业发展规划”)

December 2016 – 13th Five-Year Plan for National Informatization (“十三五国家信息化规划”)

July 2017 – 13th Five-Year development plan of LED lighting industry

Local Government Documents after 13th Five-Year

November 2017 – Three-Year (2017-2019) Guidance on Developing Smart Censor Industry (“智能传感器产业三年行动指南 [2017-2019年] ”)

January 2018 – Guidelines by the State Council on deepening "Internet Plus Advanced Manufacturing Industry" and Developing "Industry of Internet" ("国务院关于深化"互联网+先进制造业"发展工业互联网的指导意见")

- Briefly mentioned IC industry in implementing tax cut policies.

March 2018 – Notice on Issues concerning Enterprise Income Tax Policies for Integrated Circuit Production Enterprises (关于集成电路生产企业有关企业所得税政策问题的通知)

March 2018 – Measures on Transferring Intellectual Property Abroad ("知识产权对外转让有关工作办法 [试行] ")

- Focus on the review mechanism of transferring IC (among others) intellectual property abroad

March 2018 – Notice on Several Opinions of Pilot Programs on Issuing Stocks or Depositary Receipt in China by China Securities Regulatory Commission ("开展创新企业境内发行股票或存托凭证试点若干意见的通知")

- Pilot enterprises include IC enterprises

April 2018 – Key Points on Standardization of Communications Industry 2018 ("年工业通信业标准化工作要点")

- Improve the promotion and application of IC standards in civil-military fusion

July 2018 – Notice on Several Measures of Optimizing Scientific Research Management and Improving Scientific Research Performance ("国务院关于优化科研管理提升科研绩效若干措施的通知")

- Increase scientific research expenditure on IC (among others)

November 2018 – To better enforce Document No. 4 in 2011, four ministries published a list of 73 companies that produce IC with the line width of less than 0.25 micrometer or the investment amount of more than 8 billion yuan and companies that produce IC with the line width of less than 0.5 micrometer.

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