Policy Brief

CSET Analyses of China's Technology Policies and Ecosystem

The PRC's Domestic Approach

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Introduction: China is Organizing at Home to Lead Abroad

At Georgetown University's Center for Security and Emerging Technology (CSET), we have made a concerted effort to understand the People's Republic of China's (PRC) approach to emerging technologies. China aspires to global leadership in numerous emerging technology areas, and understanding the steps China is taking at home and abroad to achieve its goals will allow U.S. officials to favorably shape technological and strategic competition with China. This paper focuses on China's internal actions to advance and implement its technology-related policy goals, and complements a companion brief on steps the PRC is taking abroad to become more competitive.[*]

The research summarized here is based on global tech monitoring, primary source language translations, and data analyses of private sector activity. We work to contextualize China's technology development and acquisition strategies alongside those of the United States and its global allies and partners, and to situate the U.S.-China rivalry in the broader landscape of democratic and authoritarian technology competition.

Key Themes

We identify several high-level, strategic themes from China's domestic efforts to achieve global leadership across numerous emerging technology areas:

- **China's rapid progress in talent development and acquisition.** China hopes to overtake the United States in terms of talent acquisition, in areas including STEM PhDs graduated, AI education, and centralized talent tracking programs. Its advances could prove worrisome to long-term U.S. national and economic security and competitiveness.

- **China's unique and evolving tech ecosystem.** China's tech ecosystem is evolving to more closely resemble other innovation ecosystems through its rapidly developing patent system and new policy mechanisms. However, it retains unique characteristics, particularly the close linkages among military, private sector, and public sector research under its military-civil fusion policy.

[*] See "CSET Analyses of China's Technology Policies and Ecosystem: The PRC's Efforts Abroad," Center for Security and Emerging Technology, September 2023.

- **State actions to boost China's innovation infrastructure and develop technological self-sufficiency in key areas.** China is increasing the number of publicly and privately backed research facilities working on emerging capabilities, particularly State Key Laboratories, and is experimenting with mingling industrial facilities in AI and biotechnologies that could potentially amplify research impact. The PRC also aims to lessen its dependence on foreign technology and supply chains in semiconductors.

U.S. Policy Options

To address these developments in China's domestic ecosystem, CSET's research offers U.S. policymakers practical steps for maintaining and growing tech competitiveness:

- **When it comes to remaining competitive with China in AI education, the United States should leverage the unique advantages of its comparatively decentralized system and approach.** The United States' decentralized approach to AI education does not necessarily pose an inherent disadvantage compared to the PRC. In fact, diverse curricula and standards could actually provide an advantage in fostering innovation.

- **To fortify the U.S. and its allies' and partners' dominance in the advanced chip manufacturing necessary for AI and other emerging technologies, the United States should adopt "protect" and "promote" policies around semiconductor manufacturing equipment export and production.** Adopting these policies could keep China from becoming a critical part of the supply chain or a critical source of semiconductor technology and manufacturing (especially high-end materials and manufacturing equipment) for the next 20-30 years. The United States has already begun to make strides in this area with the 2022 CHIPS and Science Act.

- The U.S. should also focus on **developing and retaining its talent pipeline, particularly access to foreign skilled labor that comprises** about 40% of the U.S. semiconductor industry workforce. It should consider **increasing country-based caps on annually distributed employment-based green cards**, and generally try to **expand the number of American students who are in semiconductor-related graduate programs**.

- **As China continues to make domestic strides, the United States will need to think strategically about the areas in which it attempts to decouple from China, including the advantages and disadvantages of doing so in different areas.** The effectiveness of decoupling efforts may depend on the particular characteristics of different technologies.

The brief begins with a look into how CSET conducts its China-related research, it examines the themes mentioned above, and concludes with recommendations. Overall, the underlying CSET research provides a higher-resolution picture of China's efforts in these areas with illustrative examples and data-backed analysis. Readers are encouraged to consult source reports for greater detail.

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Research Context for CSET's Work on China's Domestic Tech Policies

At the Center for Security and Emerging Technology (CSET), we develop a data and primary-source informed understanding of the People's Republic of China's (PRC) approach to emerging technologies. We analyze how this approach affects the United States and how U.S. policies can in turn favorably shape technological and strategic competition with China. Our analytical products incorporate global tech monitoring, primary source language translations, and data analyses of private sector activity, helping contextualize China's technology development and acquisition strategies alongside those of the United States and its global allies and partners. Our work also situates the U.S.-China rivalry in the broader landscape of democratic and authoritarian technology competition.

This analysis derives from several CSET papers that address these topics in greater detail, with a particular emphasis on higher STEM education, military-civil fusion, talent recruitment, and policy innovation and experimentation, among several other topics relevant to policymakers. See Table 1 for more details.

Table 1. CSET Papers Cited in this Brief and Their Author(s)

Report	Author(s)
Academics, AI, and APTs	Dakota Cary
AI Education in China and the United States	Dahlia Peterson, Kayla Goode, and Diana Gehlhaus
China's Industrial Clusters	Anna Puglisi and Daniel Chou
China's Progress in Semiconductor Manufacturing Equipment: Accelerants and Policy Implications	Will Hunt, Saif M. Khan, and Dahlia Peterson
China's State Key Laboratory System	Emily Weinstein, Channing Lee, Ryan Fedasiuk and Anna Puglisi
China is Fast Outpacing U.S. STEM PhD Growth	Remco Zwetsloot
Chinese and U.S. University Rankings: A Lens into Top Universities and Their Graduates	Jack Corrigan and Simon Rodriguez
Chinese Government Guidance Funds	Ngor Luong, Zachary Arnold, and Ben Murphy
The Chipmakers: U.S. Strengths and Priorities for the High-End Semiconductor Workforce	Will Hunt and Remco Zwetsloot
Chokepoints: China's Self-Identified Strategic Technology Import Dependencies	Ben Murphy
A Competitive Era for China's Universities	Ryan Fedasiuk, Alan Omar Loera Martinez, and Anna Puglisi
Counting AI Research: Exploring AI Research Output in English- and Chinese-Language Sources	Daniel Chou
Decoupling in Strategic Technologies: From Satellites to Artificial Intelligence	Tim Hwang and Emily Weinstein
Downrange: A Survey of China's Cyber Ranges	Dakota Cary

Maintaining China's Dependence on Democracies for Advanced Computer Chips	Saif M. Khan and Carrick Flynn
Patents and Artificial Intelligence	Patrick Thomas and Dewey Murdick
Securing Semiconductor Supply Chains	Saif M. Khan
The Semiconductor Supply Chain: Assessing National Competitiveness	Saif M. Khan, Alexander Mann, and Dahlia Peterson
Universities and the Chinese Defense Technology Workforce	Ryan Fedasiuk and Emily Weinstein
Using Machine Learning to Fill Gaps in Chinese AI Market Data	Zachary Arnold et al.

CSET's Unique Analytical Approach to China Research

CSET's analytical approach draws on Chinese language translation, data-driven research, and subject matter expertise in areas like semiconductors, cybersecurity, and patents that differentiates our work in the issue areas mentioned above.

- **CSET's work draws extensively on primary source translation**. We employ researchers and analysts with Chinese language skills and have developed **over 500 original translations** of Chinese policy documents through our translation pipeline. CSET's merged corpus of scholarly technology literature also draws on Chinese-language publications, which provides a more granular picture of Chinese research output.[1]

- **CSET employs methods like AI and machine learning (ML) tools to "scrape" Chinese language documents related to technology investments.** For example, our team used a natural language ML processing model to find AI-related Chinese companies missing from two leading commercial datasets, Crunchbase and PEData/Zero2IPO, which contributed to a richer picture of China's AI sector.[2]

- **Finally, we employ technical subject matter experts in research areas directly tied to the U.S.-China AI competition, including semiconductor manufacturing, cybersecurity, export controls, and patent issues.** Our fellows and analysts draw on government, academic, and private sector experiences that inform their insights and research across the thematic areas discussed in this brief.

Chinese Talent Development and Discovery Efforts

Analyzing China's efforts to develop or acquire tech talent capable of creating cutting-edge capabilities represents an important aspect of our work, and a useful starting point for looking at domestic steps the PRC is taking to augment its competitiveness. China is making strides to overtake the United States in tech talent, in areas including educational investments and STEM PhDs graduated, AI educational programs ("AI education"), and centralized talent tracking programs. Its progress in these areas could prove worrisome for U.S. national and economic security and competitiveness in the long-term.

Robust STEM PhD and AI Talent Pipelines

Improvements in China's education system, particularly in higher education, represent strategic steps to improve the country's domestic innovation ecosystem. Given its military-civil fusion policy, an approach to technology acquisition intended to provide the PRC's military easier access to cutting-edge research and technology emerging from the civil sector,[3] improvements in the quality of Chinese higher education and talent could also contribute to new military and intelligence capabilities. Analyzing how China and the United States compare can help policymakers understand the competitive challenge the former poses to the latter.

From 2012 to 2021, total central government funding for higher education in China has more than doubled, with Ministry of Education spending exceeding $179 billion. Funding for the country's best-known universities has increased each year since 2017, and individual institutions' budgets now exceed $5 billion. These funding increases stem from China's long-term science and technology (S&T) strategy, an important component of which entails revitalizing the country's elite universities. These universities are closely integrated with the Chinese political and defense establishments and dominate China's civilian basic research ecosystem; since they often serve as touchpoints for international collaboration, this could create security concerns for foreign partnering institutions. Elite Chinese universities now have comparable budgets to their U.S. counterparts.[4]

In this context, China's educational ecosystem has become highly competitive with that of the United States. It is pulling away in the number of science, technology, engineering, and mathematics (STEM) PhDs produced and will likely graduate nearly twice as many as the United States by 2025 (77,000 to 40,000).[5] The quality of Chinese PhD graduates also appears to be rising and China's STEM PhD talent pipeline is becoming more robust. Given the scale of China's investments in higher education, the gap in STEM PhD production could undermine U.S. long-term economic and national security.[6]

STEM talent is an increasingly critical national asset given the rise of AI and other emerging tech. PhD-level experts are a small, but important, component of the STEM workforce, spearheading R&D efforts that push the boundaries of their fields and educate future science and technology leaders.[7] The quantity and quality of a country's PhD graduates are important indicators of its future competitiveness.[8] China has consistently produced more STEM PhDs than the U.S. since the mid-2000s. Currently, Chinese universities graduate roughly three STEM PhDs for every two graduated by U.S. universities each year.[9]

In terms of quality, CSET research has demonstrated that Chinese universities are steadily climbing different global university rankings because of increasing measures of research output, which can serve as a proxy indicator of a PhD program's educational quality. In one ranking, the number of Chinese universities in the top 500 global universities more than tripled from 23 to 71 between 2010 and 2020.[10] **A large share of recent Chinese PhD graduates come from universities with high quality standards**. About 45 percent of Chinese PhDs graduate from the country's elite Double First Class (A) universities.[11] The number of students entering PhD programs at such institutions rose about 34 percent from 2015 to 2019 and accounted for roughly 65 percent of the total increase in first-time PhD enrollments across China in that period.[12] Economic signals suggest Chinese PhD production is not perfectly matched with labor market needs. However, **the number of elite university graduates, the institutions' growing international reputations, and the fact that over three-quarters of Chinese PhDs specialize in STEM fields indicates China's STEM talent pipeline is becoming more robust**.[13]

As the country's broader STEM talent pipeline solidifies, **China is centralizing its efforts to expand AI education at all levels, granting it a higher likelihood of developing a strong talent base to solve future AI challenges.** Standardized curricula, centralized AI education implementation plans, and company-university collaborations benefit China's AI talent pipeline. Western companies such as Microsoft Research Asia have worked with Chinese universities—including the Seven Sons, closely linked to the PRC's defense sector and discussed more below—through formalized partnerships involving curricula development. In comparison, the decentralized U.S. approach to education integration is more piecemeal and is heavily focused on tackling computer science education over AI. Recent years have seen a flurry of U.S. initiatives, programs, and private companies emerge in the AI education space, but the United States lacks a cogent vision and cohesive national standard to guide such efforts compared to China.[14]

Linking Civilian and Defense Research under Military-Civil Fusion

Equipping Chinese graduates with cutting-edge education, skills, and training is but one aspect of how the PRC's universities benefit the state. **Under military-civil fusion, China uses close relationships between universities and the government to translate cutting-edge research into security policy and shorten the path to operationalizing new techniques, both for defensive and offensive capabilities.**[15] China's "Seven Sons of National Defense," universities administered directly by the Ministry of Industry and Information Technology, provided three quarters of graduates recruited by defense state-owned enterprises in 2019.[16] Chinese state-owned defense firms directly hired a combined 6,000 graduates from 29 leading Chinese universities in 2019, a 0.3 percent increase over their estimated 2018 workforce of 2.1 million people. Nearly two-thirds of graduates bound for the defense industry (3,725 people) took jobs at the three largest state-owned electronics and aerospace companies: China Electronics Technology Group (CETC), Aviation Industry Corporation of China (AVIC), and China Aerospace Science and Technology Corporation (CASC).[17]

Documents from the Chinese Ministry of Education indicate that the Seven Sons have benefited from training programs and partnerships with the China-based subsidiaries or joint ventures of Autodesk, Dell, Google, Honeywell, IBM, Intel, Merrill Lynch, Microsoft, National Instruments, Rockwell Automation, Synopsys, Tektronix, and Texas Instruments, raising questions about how U.S. companies may be benefitting China's defense industry.[18] While the Seven Sons are important feeders for China's military and defense industry, it appears that the vast majority of civilian universities in China maintain at least some connection to the country's defense industry.[19]

China's universities have also collaborated with the security services and Advanced Persistent Threat (APT) actors on cyber research, techniques, and operations, including offensive tactics.* CSET conducted a study of six universities that had:

1. previously conducted cyber operations (Hainan University, Southeast University, and Shanghai Jiao Tong University);
2. partnered with specific divisions of the security services that conduct cyber operations (Xidian University); or,
3. were noted by U.S. cyber threat intelligence companies as places of recruitment for APTs (Zhejiang University and Harbin Institute of Technology).[20]

Our research found that the integration of universities and state-sponsored espionage shortens the time required to turn academic research into operational capabilities. It also hints at operators' possible research priorities by examining certain universities' current research. For example, the six universities mentioned above research the intersections of AI/ML and offensive and defensive cyber operations; students at the universities pick up government-relevant skills by using these capabilities for hacking while security services exploit university expertise.[21]

Universities have also collaborated with technology laboratories and companies to run cyber ranges supporting the PLA and military-civil fusion. Ranges are interactive environments with hardware and software components that can be used for talent development and to test different cyber capabilities. China's development of cyber ranges points to its desire to harness both military and civilian cyber talent that can carry out operations or conduct cutting-edge research in areas like AI cybersecurity applications.[22]

National Talent Recruitment and Tracking Programs

In addition to the significance of its universities for producing talent and supporting the security services, China is also cultivating talent recruitment and tracking at different

* Advanced Persistent Threat (APT) actors typically refers to state-affiliated cyber attackers who display exceptional technical proficiency and capability. Some sophisticated criminal groups can approach such levels, but are generally suspected of affiliation with nation-states.

administrative levels in its mission to discover and harness potential talent and technological breakthroughs.

China employs a range of talent recruitment programs from the State and Party levels down to the local level focused on cultivating and exploiting its growing domestic talent pool to support China's strategic civilian and military technology goals. China also looks to recruit talent and knowledge from abroad through these programs.[23] Beijing views these programs as vital to China's economic innovation and growth, as well as social development, aiming to recruit everyone from experts to students of both Chinese and non-Chinese citizenship for positions spanning government, industry, defense, and academia.

The Thousand Talents Plan has recently come under increasing scrutiny from Justice Department indictments and Congressional reports, but Chinese talent initiatives far exceed the scope and scale of this program alone. Other illustrative examples include the "Support Plan for Overseas Chinese Students Who Return to Start Businesses," active since 2009, which offers funding to new start-ups legally represented by a returned overseas student with a masters' degree or higher. The start-ups receive a one-time award of 500,000 RMB if classified by the Ministry of Human Resources and Social Security as a "Key Entrepreneurial Project" and 200,000 RMB if determined to be an "Outstanding Entrepreneurial Project." The "International Training Program for Artificial Intelligence Talents in Chinese Universities: Expert Forum," established in 2018, is another international networking program that brings together 30 internationally-renowned AI experts to teach a group of 300 academic and commercial participants on various AI-related subjects.[24]

In addition to the 43 national-level programs in CSET's tracker, including the two examples listed above, more than 200 talent programs exist at sub-national levels, and the number is growing and shifting constantly as Beijing seeks to retain, manage, and recruit talent globally.

China's Unique and Evolving Tech Ecosystem

The ecosystem into which China incorporates the talent described above is unique and evolving. While the extent of its military-civil fusion policy and its malign behavior, including rampant IP and data theft, are specific to the PRC, in other ways China's tech ecosystem is changing to more closely resemble U.S. and European innovation ecosystems. This is due to factors like its rapidly maturing patent system and the adoption of new policies like public-private funding mechanisms. Yet global tensions stemming from its more disruptive practices and geopolitical positioning are forcing China to take a creative approach to cultivating its domestic innovation base and to seek self-sufficiency in strategic technologies, especially semiconductors.

Maturing Patent System

China's patent system—a marker of its AI innovativeness and the perceived economic value of research—is changing rapidly and developing characteristics of more established patent systems. In recent years, Chinese AI patent applications have sharply risen, and while quality concerns remain, China's patent system should not be dismissed.[25] Both the number of global AI patent documents and shares of Chinese AI patent applications have risen dramatically within the last decade.[26] There were 10 times as many AI patent applications published in 2019 as in 2013 (over 5,000 to 65,000) and an almost four-fold increase in granted AI patents (over 2,000 to just over 10,000).[27]

The uptick in AI patent applications and granted AI patents mirrors broader patenting trends in China. According to the Chinese National Intellectual Property Association (CNIPA), the number of invention patent applications it received increased by more than 500 percent between 2009 and 2019, from 241,000 to 1.4 million. Most of the Chinese patenting increase stems from domestic, rather than international, applications; of 1.4 million CNIPA applications in 2019, domestic sources filed almost 90 percent (compared to 48 percent of USPTO applications). For comparison, the number of patent applications at the U.S. Patent and Trademark Office increased by only 35 percent (456,000 to 621,000) over the same period. In 2009, U.S. patent applications outnumbered PRC applications by almost two-to-one, but that ratio was reversed by 2019.[28]

Though the largest AI granted patent portfolios are still associated with IBM, Microsoft, and Google, beyond these three U.S. companies, Chinese organizations

dominate. These include companies (Ping An, Baidu, Tencent), government organizations (State Grid), and universities (Electronic Sci/Tech, Zhejiang, Xidian). The patent portfolios of these Chinese organizations currently consist almost entirely of recently published applications, rather than granted patents, making them a future space to watch.[29]

Recently, China's focus has shifted from incentivizing the sheer number of patents produced, particularly in academic institutions, to emphasize quality. **Government bodies like the PRC Ministry of Education recognize China must produce quality over a high quantity of patents, per CSET's translation of a 2020 policy document.** The policy eliminates patent application subsidies, bars using patent applications as a metric for universities to assess professors' and departments' performance, and bans ranking universities by their patent applications numbers.[30]

Overall, as a marker of innovative competitiveness, the increasing patent quantity and quality indicate that China's tech ecosystem appears poised to compete with U.S. and European ecosystems on their terms, particularly in AI.

Exploring New Policy Tools

Even as it improves its patenting, **China is also employing new mechanisms to get around flawed traditional policy tools it has previously used to support strategic industries.** Guidance funds, public-private investment vehicles to fund innovative industrial work, aim to strategically align private sector interests with the state's policy goals and produce financial returns around AI and other strategic and emerging technologies China hopes to dominate.

Central, provincial, and local government agencies are all establishing guidance funds that may invest directly in companies or projects or indirectly through other funds. Government sponsors provide 20 to 30 percent of the fundraising target, with private "social capital" investors providing the rest. As of the first quarter of 2020, Chinese officials had set up 1,741 guidance funds, with a cumulative registered target size of 11 trillion RMB (1.55 trillion USD), but these funds had only raised about 4.76 trillion RMB (672 billion USD).[31]

Guidance funds offer several strengths from a policy perspective. The funds incorporate private sector discipline and expertise, potentially reducing inefficiency and corruption associated with other policy tools, and leveraging private sector capital, information, contacts, and expert judgment beyond the government's abilities. Patient capital means funds can supply stable, long-term investment capital to technology startups during traditionally challenging scaling periods involved with high quality technologies. Funds amplify industrial policy measures by providing or coordinating measures like state-sponsored technology parks, R&D incentives, and talent recruitment plans, making them more effective and fostering local economies of scale that help emerging and strategic businesses take off.[32]

However, guidance funds can also raise less money than planned, waste capital, fail to invest in early-stage companies as intended, fail to invest altogether, or raise insufficient funds. Structural issues include too many guidance funds overall, poor fund management, and failure to attract truly private capital or even crowding private capital out of the market. Guidance fund progress appears localized and uneven as a policy tool, but this mechanism is likely better than other, deeply flawed traditional tools the Chinese government might use to support strategic industries, like direct government ownership or cash handouts to companies favored by the state.[33]

Boosting the Domestic Innovation Base

In addition to taking policy steps to advance its domestic technology ecosystem, China is also boosting its physical innovation infrastructure. **It is increasing the number of its State Key Laboratories (SKLs), through both public and private funding efforts, to develop its domestic innovation base and talent and capitalize on foreign knowledge and technology transfers.** The PRC began to develop SKLs in the 1980s to spur defense and commercial innovation, and CSET research has found nearly 500 SKLs to be in operation today with plans to develop more. Modeled loosely on the U.S. innovation ecosystem comprising national labs, federally-funded research and development centers, and university-affiliated research centers, SKLs have evolved to become critical building blocks in China's innovation ecosystem.[34]

A number of government ministries, most prominently the Ministry of Education, are responsible for managing SKLs, which the state relies on to conduct cutting-edge research, recruit personnel and talent, and carry out academic exchanges within and outside China across the life sciences, engineering, information, and material sciences. Often, SKLs will develop or be promoted from university-affiliated research centers or corporate R&D programs, and seek to work in areas of overlapping interest among the private sector and government. In addition to their domestic benefits, SKLs present windows of opportunity to the outside world. China's SKLs have collaborated with international institutions at a higher rate than the country's overall rate of international academic collaborations. Meanwhile, SKLs remain a key part of the military-civil fusion infrastructure that intermingles civilian, academic, and military research. In light of these facts, they could pose serious research security issues for international collaborators and complicate relationships with U.S. partners without clear assessments of the potential risks and benefits of partnership.[35]

China is also exploring how emerging technologies and research areas might be used to make breakthrough discoveries and amplify each others' impacts using methods like industrial clustering of research facilities. For example, governments at the state, provincial, and local levels have experimented with physically co-locating AI and biotechnology research facilities to ease interdisciplinary collaboration. The government views these industrial clusters as a way to capitalize on AI applications that could lead to a "transformation of China from a biotech power to a biotech superpower."[36] While nascent, such research clustering and the subsequent impacts of using AI for biological discovery could have broad and concerning commercial, ethical, and national security implications.[37]

Developing Greater Self-Sufficiency in Strategic Technologies

Finally, in certain key technology areas, particularly leading-edge semiconductors necessary for advanced computing, China is heavily dependent on imports of often originating in the United States or its allies and partner nations. **As such, China hopes to achieve self-sufficiency and indigenization across the semiconductor supply chain to decrease its reliance on foreign equipment for advanced chip manufacturing.**[38] CSET research and translations have demonstrated that Chinese officials recognize major strategic technological "chokepoints" or import dependencies that could disrupt the semiconductor and other vital industries.[39]

Efforts to develop self-sufficiency in chips could pose a long-term threat to the collective technological edge and dominant market share enjoyed by the U.S. and its allies in virtually all segments of the semiconductor supply chain. Though China currently contributes only 6 percent of value-add to the global semiconductor supply chain,[40] it is projected to become the world's largest semiconductor manufacturer by 2030.[41] While it is strongest in Assembly, Test, and Packaging (ATP), including tools for semiconductor assembly and packaging and raw materials, China will need access to a range of linchpin technologies (advanced chip-making equipment, design software, IP for advanced chips)[42] currently made in the United States and allied countries in order to reach the leading edge in manufacturing. [43]

China is exploring several methods and possibilities for expediting its semiconductor manufacturing equipment (SME) independence. One is by **importing equipment components**, since many of the specialized components required for building SME are made either in the U.S. or in a U.S.-allied country. China is trying to indigenize these components to avoid controls, with an emphasis on photolithography tools. Another method is by providing government **subsidies** to SME firms. China is likely to ramp up its assistance to its fledgling SME industry and may improve its fund investment management in the coming years. As of now, the National Integrated Circuit Industry Investment Fund, or “Big Fund,” has invested $950 million in Chinese SME firms, although poor management has limited its benefits.[44]

Explicit and tacit knowledge transfers could also benefit China’s domestic chip industry. **Explicit knowledge** efforts involve reverse engineering, along with IP theft and corresponding extralegal methods of obtaining engineering knowledge, and China’s expected to increase in the coming decade. Capitalizing on **tacit know-how** involves drawing on the knowledge of Chinese nationals employed at foreign SME firms who return to China with valuable information to contribute to the SME indigenizing effort. It should be noted, though, that of the approximately 1,100 Chinese nationals working at SME firms outside of China, very few have or are expected to join Chinese SME firms.[45]

Finally, partnerships **and collaboration between Chinese SME firms and fabs** could spur on indigenization efforts. Chinese SME firms are currently experiencing difficulty finding buyers — in the form of chip fabrication facilities — that are open to collaborating on the refinement process. If they can build these collaborative relationships in the future, China would be able to catch up to the U.S. and allies and reduce their competitive advantage in SME.[46]

Relevant Recommendations for U.S. Policy

Some of the steps China is taking at home to augment its technology policies and ecosystem may present challenges to the United States amid strategic and technological competition. CSET's research and analyses have produced a number of recommendations related to the discussion above to help U.S. policymakers navigate this competition, particularly in areas such as strategy, export controls, and education. Goals include ensuring the United States does not lag behind China in producing talent and developing cutting-edge capabilities, as well as safeguarding the responsible development of new capabilities.

- **When it comes to remaining competitive with China in AI education, the United States should leverage the unique advantages of its comparatively decentralized system and approach.** The United States' decentralized approach to AI education does not necessarily pose an inherent disadvantage compared to the PRC. In fact, diverse curricula and standards could actually provide an advantage in fostering innovation. Greater U.S. educational autonomy allows room for experimentation, creativity, and innovation among companies and educational institutions. The challenge lies in successfully evaluating and scaling these experiments and initiatives throughout the entire education system.[47]

  To leverage this advantage, U.S. states will need to engage in targeted and coordinated efforts with unprecedented levels of support for long-term AI educational and workforce policies. U.S. AI education efforts will be the most effective with consistent application over time, unaffected by the election cycle, with assured state and local access to the requisite resources for schools, educators, and students.

  In addition, the future U.S. S&T education and workforce policy should be considered in a globally competitive context. That consideration includes recognizing and capitalizing upon the U.S.'s enduring advantage in attracting elite foreign talent, including Chinese nationals.[48]

- **To fortify the U.S. and its allies' and partners' dominance in the advanced chip manufacturing necessary for AI and other emerging technologies, the United States should adopt "protect" and "promote" policies around semiconductor manufacturing equipment export and production.** Adopting these policies could keep China from becoming a critical part of the supply chain or a critical source of semiconductor technology and manufacturing (especially high-end materials and manufacturing equipment) for the next 20-30 years. The United States has already begun to make strides in this area with the 2022 CHIPS and Science Act.[49]

Aspects of "protect" policies include **export controls**, which can be targeted towards **chokepoints** (SME, Electronic Design Automation software, etc.)—aspects of the semiconductor supply chain for which China lacks the ability to construct advanced chip factories and to indigenize chip production. In addition, export controls can be applied to **specific end-use and end-user** (Chinese semiconductor firms, military) to target entities in China that are using semiconductors to power advancements in military modernization or surveillance technologies. Previous CSET research recommended that the U.S. government **monitor AI chip end uses** through reporting requirements to identify purchasers and the types and numbers of chips (server-grade CPUs, FPGAs, AI training ASICs) sold for exports, re-exports, and in-country transfers to or within countries of concern.[50]

This research also argued that the U.S. government should **impose (1) direct export controls** on advanced chips, **(2) controls on re-exports** of such chips, and **(3) a vetting regime** for large cloud computing purchases where China or others use chips to harm international security or human rights. In October 2022, the U.S. government announced new export controls on the sale of advanced semiconductors, including but not limited to the aforementioned AI chips and related equipment, to restrict the ability of Chinese entities to use advanced chips for military modernization and human rights abuses. The U.S. government is now working across several international fora to promote the multilateralization and plurilateralization of these export controls, in line with previous CSET recommendations to work with allies and partners to secure the chip supply chain.[51]

On the "promote" side of the ledger, the United States and its allies should continue to push the leading edge forward by **funding R&D, increasing financial incentives to chipmakers, developing and retaining the talent pipeline, and preventing and reducing technology transfer.** Domestically, effectively implementing the CHIPS and Science Act funding is the most urgent item on the "promote" agenda. **Top-tier "promote" priorities** include **attracting chipmakers to the U.S.** to mitigate the high probability of an extremely costly disruption in high-end imports from East Asia (especially Taiwan). In addition, **allocating funding to**

offset potential losses from export control policies that slow China's chip manufacturing will be important. **$2 billion of funding** would help offset losses to U.S. and ally firms.[52] **Reducing the costs of operating an advanced logic or memory fab down to $20-22B, in conjunction with new incentives of $3-5B per fab,** will help to close the gap with Taiwan, South Korea, and China, who offer large incentives to their chipmakers.[53]

- The U.S. should also focus on **developing and retaining its talent pipeline, particularly access to foreign skilled labor that comprises** about 40 percent of the U.S. semiconductor industry workforce. It should consider **increasing country-based caps on annually distributed employment-based green cards**, and generally try to **expand the number of American students who are in semiconductor-related graduate programs**. To do so, policymakers should allocate funding to universities and government-industry-academic partnerships to facilitate the increased implementation of on-the-job training models.[54]

- **As China continues to make domestic strides, the United States will need to think strategically about the areas in which it attempts to decouple from China, including the advantages and disadvantages of doing so in different areas.** The effectiveness of decoupling efforts may depend on the particular characteristics of different technologies. For example, attempting to totally decouple from China in AI could prove challenging given the diffuse nature of AI/ML supply chains. The export controls on high-end logic and memory chips imposed by the Biden Administration in October 2022 are intended to limit China's access to the computing power necessary for advanced AI systems. However, advancements in algorithmic development and data processing, the other two legs of the "AI triad" (data, algorithms, and computing power) could offer alternative pathways toward powerful AI and ML capabilities, and decoupling might incentivize China to invest in low compute ML research.[55]

  Similarly, applied without sufficient support from allies and partners, foreign direct product rules controlling Chinese-developed technologies for national security purposes, could lead foreign companies to remove U.S. tools, content, and intellectual property, from their products and manufacturing processes. This would harm U.S. interests in the long run. The United States will need to continually monitor the effectiveness of decoupling techniques and ensure ongoing support from and cooperation with the allies and partners who are critical to limiting Chinese access to key technologies.

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Endnotes

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[12] Zwetsloot et al., "China is Fast Outpacing U.S. STEM PhD Growth," pp.6.

[13] Zwetsloot et al., "China is Fast Outpacing U.S. STEM PhD Growth," pp.8.

[14] Dahlia Peterson, Kayla Goode, and Diana Gehlhaus, "AI Education in China and the United States," (Center for Security and Emerging Technology, September 2021), pp.38-39, https://cset.georgetown.edu/publication/ai-education-in-china-and-the-united-states/

[15] Dakota Cary, "Academics, AI, and APTs," (Center for Security and Emerging Technology, March 2021), pp.25, https://cset.georgetown.edu/publication/academics-ai-and-apts/

[16] A source note from page 9: based on the study's approach, foreign observers of the United States could describe U.S. universities like Carnegie Mellon, the University of Arizona, or Georgia Tech as "defense affiliated" because their graduates frequently take jobs at Honeywell, Lockheed Martin, or Raytheon. There are fundamental differences between the U.S. and Chinese higher education systems, and U.S. defense companies are not state-owned. But policymakers should carefully consider the political and scientific costs and benefits of labeling certain universities as "defense-affiliated." Ryan Fedasiuk and Emily Weinstein, "Universities and the Chinese Defense Technology Workforce" (Center for Security and Emerging Technology December 2020), pp. 3,9, https://cset.georgetown.edu/publication/universities-and-the-chinese-defense-technology-workforce/

[17] Fedasiuk and Weinstein, "Universities and the Chinese Defense Technology Workforce," pp. 9-10.

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[19] It is worth noting for comparison that a number of U.S. universities like Carnegie Mellon, Georgia Tech, or the University of Arizona could be considered defense affiliated under these criteria given their links to industry and the high number of graduates they send to defense contractors. Fedasiuk and Weinstein, "Universities and the Chinese Defense Technology Workforce," pp. 3-9. In addition, according to U.S. Department of Defense sources, over U.S. 1,700 colleges and universities host Reserve Officers' Training Corps (ROTC) programs linking to the U.S. military services, technically giving them at least some connection to the DoD. See Today's Military, "ROTC Programs," U.S. Department of Defense, 2023: https://www.todaysmilitary.com/education-training/rotc-programs.

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[26] CSET and 1790 Analytics created a database containing all AI granted patents and published applications (collectively "patent documents") between January 2000 and March 2020 in all patent systems worldwide. Our AI patent database contains 287,532 patent documents (230,855 published applications and 56,677 granted patents). Thomas and Murdick, "Patents and Artificial Intelligence," pp.8-9.

[27] Thomas and Murdick, "Patents and Artificial Intelligence," p. 13.

[28] Thomas and Murdick, "Patents and Artificial Intelligence," p. 10-12.

[29] Thomas and Murdick, "Patents and Artificial Intelligence," p. 14.

[30] Certain Opinions of the Ministry of Education, the China National Intellectual Property Administration, and the Ministry of Science and Technology on Improving the Quality of Patents at Institutes of Higher Education and Promoting [Patent] Conversion and Use (Translation, Center for Security and Emerging Technology, March 2021), p 1., https://cset.georgetown.edu/wp-content/uploads/t0271_no_univ_patent_subsidies_EN.pdf

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[32] Luong, Arnold, and Murphy, "Chinese Government Guidance Funds," pp. 4-5.

[33] Luong, Arnold, and Murphy, "Chinese Government Guidance Funds," pp. 5-9.

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[48] Peterson, Goode, and Gehlhaus, "AI Education in China and the United States," pp.39-40.

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[50] Khan, "Securing Semiconductor Supply Chains," p. 30.

[51] Khan, "Securing Semiconductor Supply Chains," p. 27-30.

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[53] Taiwan and South Korea are the primary manufacturers of leading-edge logic chips. Antonio Varas et al., "Government Incentives and US Competitiveness in Semiconductor Manufacturing" (Boston Consulting Group and Semiconductor Industry Association, September 2020), pp.1, 35, https://web-assets.bcg.com/27/cf/9fa28eeb43649ef8674fe764726d/bcg-government-incentives-and-us-competitiveness-in-semiconductor-manufacturing-sep-2020.pdf.

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