Restrictions to Resilience: Lessons from China’s Response to Semiconductor Export Controls

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Abstract:

Export controls represent a critical tool in economic statecraft, strategically deployed to limit adversaries' technological advancement. However, their long-term effectiveness at inhibiting Chinese semiconductor production remains uncertain, as these restrictions might redirect rather than halt innovation. This paper addresses the problem of evaluating how export controls influence global supply chains, specifically questioning whether these measures when applied to China effectively achieve strategic containment or inadvertently accelerate efforts toward technological self-sufficiency in targeted economies.

Employing a survey of Chinese adaptations to export controls on semiconductors combined with a structured assessment using the STORM (Strategic, Technological, Organizational, Regulatory, and Market) framework, this study examines China's semiconductor sector's adaptation to export controls. The methodology integrates an assessment of policy shifts, strategic financial investments, and innovative workforce development initiatives, leveraging insights from this analysis, Technology Policy, and China Studies.

The paper's primary contribution lies in its comprehensive assessment of export control effectiveness, providing nuanced insights into the complex interaction between international regulatory constraints and national industrial responses. This research advances the discourse on economic policy by illustrating the intricate and often counterintuitive outcomes of export control policies within the global semiconductor ecosystem.

Key insights from this analysis reveal that while export restrictions aim to curtail China's technological capabilities, their unintended consequences include bolstering China's domestic capacity-building and driving alternative innovation pathways. Consequently, China's semiconductor industry demonstrates resilience, evolving beyond reactive measures into proactive strategic adaptations.

This study contributes to the fields of innovation and strategic autonomy by evaluating how export controls reshape national industrial systems. By integrating cross-domain indicators—financial, organizational, and human capital—under a unified STORM framework, the research offers a novel approach to assessing sovereign technological resilience.

Introduction:

Export Controls and Strategic Competition

The global semiconductor industry stands at the forefront of the intensifying geopolitical rivalry between the United States and China. Within this strategic context, export controls have emerged as critical tools of economic control, aimed at constraining adversarial technological advancements by restricting access to essential technologies. However, the long-term effectiveness of these restrictions remains uncertain, as evidence suggests they may redirect rather than halt innovation, potentially accelerating self-sufficiency initiatives within targeted economies.

This paper advances current debates on export control efficacy by evaluating the strategic implications of export controls in the context of U.S.-China semiconductor competition. Specifically, it contextualizes the current rivalry through a comprehensive literature review, synthesizing scholarly perspectives on technological competition, trade restrictions, and national innovation strategies. It then presents a structured survey of Chinese adaptations to export controls on semiconductors across three distinct phases (I–III) of China's semiconductor industry development, highlighting critical turning points shaped by evolving regulatory frameworks and state-directed industrial strategies. The methodology applies a structured, case-based framework combining policy tracing and triangulated qualitative data across five STORM domains: Social, Technical, Organizational, Regulatory, and Market.

Finally, the study provides targeted policy recommendations for the United States, informed by a nuanced understanding of export controls' complex dynamics and their broader implications for global technological competition. By integrating historical insights, theoretical perspectives, and practical policy analysis, this research clarifies the challenges and opportunities facing policymakers engaged in the strategic management of technological competition.

Literature Review: Regulatory and Industrial Policy Foundations

The effectiveness of export controls as instruments of economic containment continues to spark significant scholarly debate within political economy and technology policy literature. Policymakers typically frame export controls as strategic tools to curb adversarial innovation. However, scholars argue these restrictive trade mechanisms often arise from broader concerns over relative economic gains, consequently prompting targeted economies to implement adaptive measures aimed at enhancing homegrown technological capabilities and mitigating reliance on external markets (Tyson, 1992; Mastanduno, 1991).

Historical examples highlight the nuanced nature of export controls. During the Cold War, the Coordinating Committee for Multilateral Export Controls (COCOM) successfully restricted sensitive technology transfers to the Soviet bloc, benefiting from limited trade integration among communist sovereignties (Marx, 2023). Following COCOM's dissolution, the establishment of the Wassenaar Arrangement in 1996 intended to control dual-use technologies globally. However, scholars note its limited effectiveness due to weak enforcement and uneven adoption, resulting in regulatory gaps China skillfully navigated via third-party supply chains and indirect market acquisitions (Roberts et al., 2021; Breznitz and Murphree, 2011). Unlike previous eras, contemporary U.S. unilateral restrictions against China contend with deeply integrated global supply chains, increasing complexity in enforcing effective controls (Chen, 2023).

Researchers in political economy and industrial policy increasingly emphasize that export controls often reshape, rather than halt, technological progress. Breznitz and Murphree (2011) argue that China's adaptive innovation system can reroute technological advancement through internal ecosystems when faced with external constraints. Similarly, Naughton (2018) highlights China's capacity for rapid reallocation of resources and capital due to its state-driven industrial policies, further enhancing flexibility against trade restrictions.

Recent U.S. policies under the Biden administration, notably the CHIPS and Science Act of 2022, represented a significant shift from market-driven technology development toward a state-backed semiconductor approach similar to how China has grown their industrial base. This proactive approach seeks long-term supply chain adaptibility but also mirrors China's industrial policy model, creating a scholarly debate about the effectiveness and long-term implications of this strategic shift (Goujon and Reynolds, 2024).

Despite initial setbacks from export controls, China's semiconductor sector rapidly adapted through state-directed financing, strategic stockpiling, and targeted talent acquisition. Initiatives such as the Thousand Talents and Qiming Programs underscore a long-term commitment to technological self-reliance, reinforcing scholarly perspectives on state-centered industrial adaptation (Min and Wei, 2024; Yang and Potkin, 2024).

While existing research offers valuable insight into policy evolution and adaptive mechanisms, gaps remain in quantitatively assessing the economic impact of export controls—particularly regarding trade flow restructuring, capital movement, and innovation displacement. Historical trade models represent promising methodologies for future inquiry, but few studies apply them directly to the semiconductor sector.

This study addresses that gap by proposing a framework to trace changes in trade dynamics, financial flows, and workforce structuring—anchored in the strategic deployment of China's Integrated Circuit Industry Investment Fund. The following sections offer a phase-by-phase analysis of China's evolving industrial response, grounded in both theoretical and empirical perspectives introduced above.

China's Strategic Adaptation: State-Sanctioned Investment and Workforce Expansion

China's response to US semiconductor and AI enabled hardware restrictions (ECCN 3A090.a and 4A090.a) has relied on two primary pillars: targeted financial intervention and talent acquisition. The main capital fund, the ICF (the 'Big Fund') has provided structured capital for semiconductor supply chain development, encouraging the reduction of reliance on foreign firms. At the labor level, programs like the Thousand Talents Program (TTP) and Qiming Program have strengthened local expertise in semiconductor research and deployment, allowing China to compensate for limited access to international talent.

While the United States has pursued some institutional investments through programs such as the AI Institute for Advances in Optimization (AI4OPT) under the CHIPS Act, China's strategy has focused on centralized state investment and regulatory incentives. These divergent approaches highlight key differences in industrial policy, with China favoring direct intervention and the U.S. opting for decentralized, private-sector-driven solutions.

Facing escalating U.S. semiconductor restrictions, China has framed its response as an opportunity for self-sufficiency. Reinforcing state-led industrial development themes, Ministry of Foreign Affairs spokesperson Lin Jian stating, "Containment and suppression cannot stop

China’s development, but will only enhance China’s determination and ability to develop its scientific and technological self-reliance” (Jowitt, 2024).

This official message is substantiated by China’s aggressive policy realignment. The Ministry of Industry and Information Technology (MIIT) has set ambitious benchmarks, including doubling national computing power to 300 exaflops by 2025 (American Affairs Journal, 2024). Meanwhile, the latest phase of the Big Fund 3.0 allocates $47.5 billion occurring from 2024 to 2039, developing indigenous semiconductor R&D after expanding their memory capabilities, rounding out the necessities.

These initiatives underscore a core theme of China’s industrial strategy: rather than yielding to external pressure, the state leverages sanctions as a catalyst for deeper structural reforms. This aligns with economic theories of strategic trade resilience, where targeted nations respond to restrictions by intensifying domestic investment and import substitution (Tyson, 1992; Mastanduno, 1991).

As China’s self-sufficiency efforts gain traction, it is essential to assess whether export controls are achieving their intended strategic outcomes. Have these restrictions delayed China’s technological progress, or have they forced a structural realignment that, in the long run, strengthens its position in the semiconductor industry?

At the heart of China's semiconductor supply chain lies a carefully orchestrated financial strategy. The Integrated Circuit Industry Investment Fund (ICF) represents more than just a funding mechanism—it is a living blueprint for technological self-sufficiency, demonstrating how strategic capital allocation can transform external constraints into opportunities for indigenous innovation.

Despite persistent export restrictions, China’s pursuit of semiconductor self-sufficiency has advanced through state-backed financial mechanisms designed to reshape the national technology landscape. The ICF established a structured financing model that strategically allocated capital toward chip fabrication capacity, domestic supply chains, and lithography R&D (Fuller, 2021; VerWey, 2019). The People’s Bank of China (PBOC) played a central role in coordinating this investment flow, aligning financial policy with the industrial objectives described in Naughton’s account of adaptive economic governance.

To contextualize how this financial architecture evolved in response to U.S. export controls, the following section outlines a phase-by-phase breakdown of the ICF, illustrating how capital allocation has mirrored external trade pressure and internal policy recalibration.

This analysis draws on a dual-method approach: historical policy tracing and STORM-based strategic assessment. The survey of Chinese adaptations to export controls on semiconductors examines how China’s investment phases correspond with key U.S. regulatory interventions, particularly the BIS restrictions enacted in 2019 and 2022. The STORM framework—covering Social, Technical, Organizational, Regulatory, and Market conditions—captures the multidimensional nature of China’s response.

Each STORM element is supported through structured triangulation, integrating official policy records, scholarly interpretation, and independent metrics to ensure analytical rigor. In areas where direct documentation was limited—such as firm-level R&D expenditures or internal program impacts—triangulation relied on industry datasets and cross-referenced secondary sources. These methodological safeguards ensure that despite restricted visibility into certain sectors, the analysis remains grounded, reproducible, and policy relevant.

History and Analysis - Funding of Phases:

The ICF was launched on September 26, 2014, by the Ministry of Industry and Information Technology (MIIT) to direct resources into semiconductor manufacturing for planned industrial expansion including mergers and acquisitions (Caixin, 2022).

Administered jointly by the MIIT and the Ministry of Finance, the fund organized capital disbursement, responding with layered policy and industry requirements. The Big Fund evolved through three distinct phases—an overview of which is detailed below.

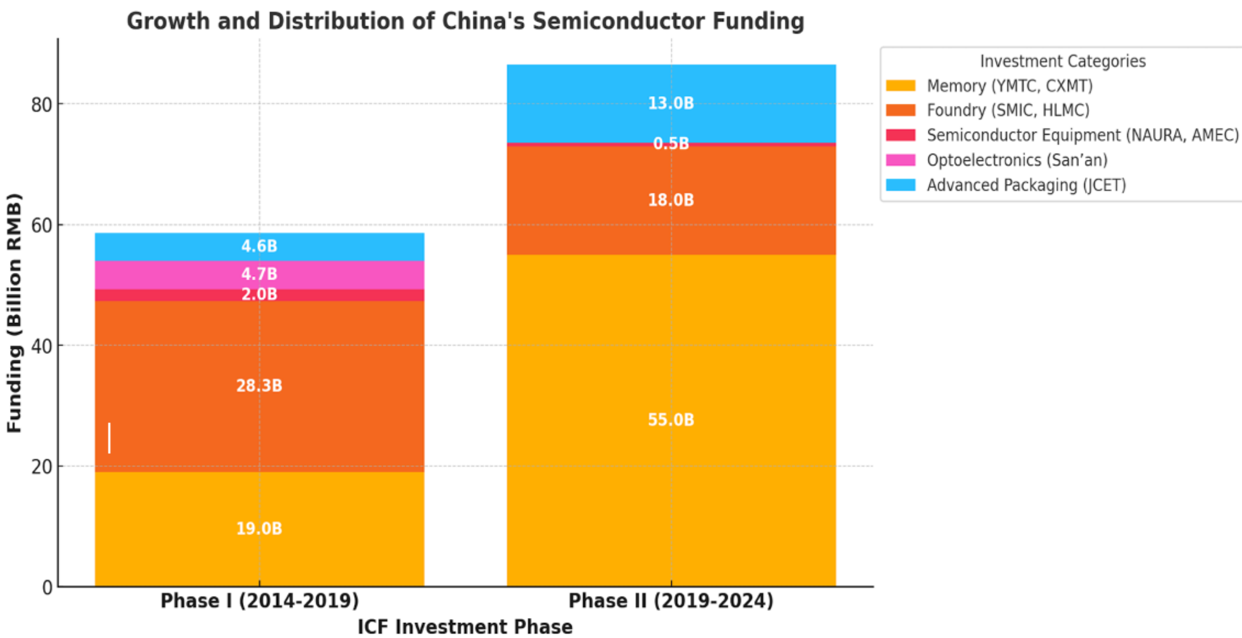
How resilient is the Chinese industrial supply chain?

After examination and summarizing each phase, policy shifts are reflected in the financial strategy revealing a reactive response to US trade controls. Data, therefore, demand planning, was shaped by varying degrees through pathways of external pressure. Underneath the surface, the overall goals of each phase developed into:

- Phase I prioritized rapid capacity-building to reduce reliance on foreign semiconductor imports.
- Phase II adapted to tightening U.S. export restrictions by reinforcing supply chain resilience.
- Phase III (2024–2039) directs investment toward advanced lithography and risk mitigation strategies to sustain long-term competitiveness amid persistent and organized embargoes.

Throughout this evolution, the ICF has demonstrated increasing institutional awareness, adjusting financial structures and investment priorities to withstand incoming economic pressure, trade restrictions, and internal setbacks. For example, in May 2024, the ICF launched its third phase with a registered capital of US$47.5 billion, securing US$15.73 billion from six major state-owned banks to bolster financial stability amid economic challenges. The third iteration includes targeted investments toward AI integrated chips, third-generation semiconductors, and advanced lithography equipment to counter U.S. trade limitations. The adaptability of fund-based operations suggests a system engineered to absorb shock and maintain strategic continuity despite constant assured volatility. Charts and tables detail the evolution of funding, sector market investment trends, and other industrial output metrics, illustrating how these financial adjustments contributed to long-term semiconductor expansion.

Figure 1. The chart below illustrates the structured disbursement of funds to support China's semiconductor supply chain expansion. This allocation highlights the fund's manufacturing focus, shaping China's early self-reliance efforts.



Author analysis based on Caixin (2022), CSC Financial, and aggregated policy disclosures.

Figure 2. Table highlights the scale of funding efforts compared to other Chinese industrial priorities

Table 5.2: Largest Industrial Guidance Funds (2020)

Fund Name	Level	Scale (Billion RMB)
Integrated Circuit Fund (both rounds)	National	338.70
Optical Valley Fund (Wuhan)	Municipal	250.00
Government-Enterprise Cooperation Fund	National	180.00
Central SOE Innovation Fund	National	150.00
Kunpeng Fund (Shenzhen)	Municipal	150.00
National SOE Adjusment Fund	National	130.00
Shanxi Taihang Fund	Provincial	105.00
Jiangxi Development and Upgrading Fund	Provincial	100.01
Beijing Investment Guidance Fund	Provincial	100.01

Sources: own elaboration compiled by the author from data supplied by Zero2IPO / Qingke Research Center (清科研究中心). Accessed at https://www.pedata.cn/. Some data may be behind paywalls.

Author analysis based on Caixin (2022), CSC Financial, and aggregated policy disclosures.

Note: Chinese Industrial Spend - This shows the margin between #1 and #2 slots.

Phase I: Laying the Foundation (2014-2019)

The base model of the ICF raised total capital of 138.72 billion yuan ($21.8 billion) and prioritized foundational investments to expedite China's semiconductor capabilities. 67% of the fund's initial capital was directed toward semiconductor manufacturing, with major contributions to leading firms such as:

- YMTC (Yangtze Memory Technologies Corporation): RMB 13.5-19 billion, primarily for memory chip production.
- HLMC (Shanghai Huali Microelectronics): RMB 11.6 billion.
- SMIC North and South (Semiconductor Manufacturing International Corporation): RMB 16.7 billion combined.
- San'an Optoelectronics: RMB 4.7 billion.
- JCET (Jiangsu Changjiang Electronics Technology): RMB 4.6 billion for advanced assembly, test, and packaging (ATP) (GF Securities, cited in Caixin, 2022).

Despite notable allocations, only RMB 2 billion—a total of 1.44% of the total fund—was dedicated to equipment development. This early oversight created a critical bottleneck in China's ability to achieve modern high-performance semiconductor production.

Phase II: Scaling and Realignment (2019-Present)

Phase II of the ICF, launched in 2019 with a capital pool of 204 billion yuan ($29.08 billion), represent expansion in scale and ambition.

Key Aspects of Phase II

- Wafer Fabrication Dominance: Investments in large-scale production facilities were a central focus of Phase II, aiming to address the capital-intensive nature of semiconductor manufacturing. This is evidenced by the significant allocations to wafer fabrication, which constituted approximately 75% of the total funds (CSC Financial, cited in Caixin, 2022). As established earlier, China's industrial responses are rooted in its capacity for rapid policy realignment and swift redirection of capital to strategic sectors like semiconductors in response to external pressures, such as U.S. export controls. Chinese policy action reflects reports detailing China's focus on accelerating their advanced manufacturing capabilities during this these years. (Naughton, 2018, The Chinese Economy: Adaptation and Growth) Furthermore, Allen (2024) emphasizes that China's semiconductor equipment capabilities, despite starting with low R and D expenditure, showed extraordinary growth during this period, aligning with the focus on large-scale fabrication facilities (Allen, 2024, The True Impact of Allied Export Controls).

- Design and ATP: RMB 18 billion was allocated to IC design companies, while RMB 13 billion supported assembly, test, and packaging (CSC Financial, cited in Caixin, 2022). These investments reflect China's broader effort to build a comprehensive semiconductor ecosystem, as evidenced by Breznitz and Murphree (2011), who argue that China's innovation system adapts to external limits by rerouting development through local supply chains (Breznitz and Murphree, 2011, Run of the Red Queen). Additionally, Cao and Pan (2023) report that, despite U.S. sanctions, firms like YMTC intensified their targeted investments in advanced chip design and packaging, highlighting a strategic response to export controls (Cao and Pan, 2023, South China Morning Post).

- Equipment Development Gap: Despite the scale of Phase II, only RMB 500 million was allocated to equipment development (CSC Financial, cited in Caixin, 2022). This underinvestment in research and development of support equipment remains a persistent challenge, as noted by Allen (2024), who points out that while China's progress in semiconductor equipment localization predates modern export controls, significant gaps persist in developing advanced tooling (Allen, 2024, The True Impact of Allied Export Controls). Similarly, Yang and Potkin (2024) highlight that China's stockpiling of foreign equipment, such as DUV lithography machines, reflects ongoing reliance on Western technology, underscoring the limitations of Phase II's equipment funding (Yang and Potkin, 2024, Reuters).

  Financial investment alone cannot guarantee technological progress. China's response to export controls extends beyond monetary commitments, encompassing a comprehensive approach to trade policy, supply chain management, and strategic repositioning that seeks to neutralize the impact of international restrictions.

Phase III: Strategic Realignment for Technological Autonomy (2024–2039)

The launch of Phase III of the Integrated Circuit Fund in May 2024 marked a pivotal shift in China's semiconductor strategy. Moving beyond reactive capacity-building, this stage reflects a more deliberate push for technological autonomy under sustained geopolitical pressure. Phase III represents a recalibrated industrial policy—one that fuses long-term innovation planning with institutional reform.

At its core is a refined investment strategy prioritizing advanced lithography, third-generation semiconductors, and AI-integrated chipsets. Approximately 40% of funding is allocated to domestic lithography development, underscoring China's intent to bridge the sub-5nm manufacturing gap by 2028. Figure 3 illustrates this allocation, highlighting the Fund's strategic emphasis on lithography, regional equity, and next-generation chip design.

While extreme ultraviolet (EUV) lithography remains a core bottleneck, Huawei and SMIC have reportedly initiated early-stage testing of indigenous EUV systems, with trial production expected by late 2025 and broader deployment projected thereafter (Lovati, 2025; Wang and Chen, 2025).

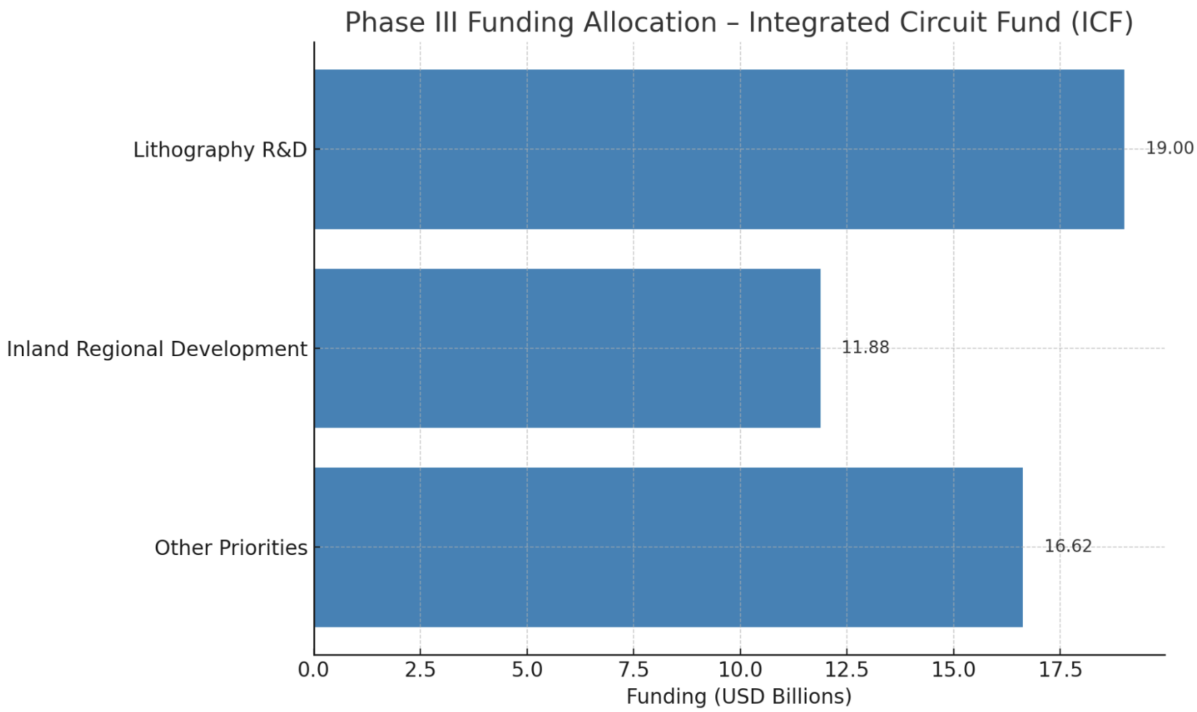
Beyond lithography, Phase III also targets third-generation semiconductors such as silicon carbide (SiC) and gallium nitride (GaN), supporting high-efficiency applications in AI, defense, and electric vehicles. These investments complement state-led efforts to strengthen domestic equipment supply chains and reduce reliance on foreign photolithography and etching technologies.

Alongside these technological priorities, Phase III also introduces a revised governance and geographic distribution model to address past structural weaknesses. Unlike earlier phases, which overwhelmingly concentrated funding in coastal hubs like Shanghai and Shenzhen, Phase III attempts a more balanced geographic strategy. Government planning documents suggest that up to 25% of total disbursements will be directed toward inland provinces, including Sichuan, Hubei, and Shaanxi—regions identified as critical nodes for regional semiconductor cluster formation and talent development (CSIS, 2021; People's Daily, 2023)

Equally significant are the governance reforms embedded in this round of funding. Following a series of high-profile corruption scandals that plagued China's semiconductor supply chain, particularly within the Integrated Circuit Industry Investment Fund (Big Fund), Phase III introduces a performance-based investment model to address systemic issues. Notable scandals include the 2021 investigation into Gao Songtao, former vice-president of Sino IC Capital, and the July 2022 arrests of Ding Wenwu, the Big Fund's chief executive, and Lu Jun, former president of Sino IC Capital, for suspected serious violations of law and discipline. These probes, intensified by the Central Commission for Discipline Inspection (CCDI), were compounded by the high-profile collapse of Wuhan Hongxin Semiconductor Manufacturing Co. (HSMC) between 2019 and 2021, where $20 billion in investments yielded no production due to mismanagement and inflated costs. The August 2022 arrests of Zhao Weiguo of Tsinghua Unigroup and Xiao Yaqing, then-Minister of Industry and Information Technology, further underscored the depth of corruption, leading to a significant stall in Big Fund investments that year. Under the guidance of Zhang Xin, new leadership has replaced the earlier centralized disbursement model with an ecosystemic framework, wherein funding is conditional on project milestones, technical viability, and alignment with national development goals, aiming to restore credibility and ensure strategic continuity (Baark & Qian, 2025; Lee, 2024; The China Project, 2022; Asia Times, 2022).

In effect, Phase III represents more than a continuation of state-sponsored semiconductor development — it is a strategic reorientation toward resilient innovation ecosystems, built to endure international constraints while fostering indigenous breakthroughs. By integrating fiscal discipline with technological ambition, China seeks not only to survive export restrictions but to restructure its innovation base in ways that render such controls increasingly ineffective over time.

Source: See references, data aggregated from Phase III collection



Author analysis based on Caixin (2022), CSC Financial, and aggregated policy disclosures.

Figure 3. Phase III ICF Funding Allocation (2024–2039):

Distribution of $47.5 billion (approx. RMB 345 billion) across lithography R&D (40%), inland regional development (25%), and other strategic priorities including AI-integrated chips and third-generation semiconductors (35%).

This represents a significant increase compared to earlier phases: Phase I totaled RMB 138.7 billion, and Phase II RMB 204 billion. Notably, while Phase II allocated only RMB 500 million to equipment development, Phase III's heavy emphasis on advanced lithography and geographic equity reflects a strategic correction. The upward trend in total investment underscores China's intensifying commitment to semiconductor self-sufficiency.

Navigating Export Controls: China's Strategic Response

Retaliatory Trade Policies and Supply Chain Adjustments

In response to escalating U.S. semiconductor export controls, China enacted wide-reaching retaliatory trade policies aimed at disrupting global supply chains. In mid-2023, China imposed export restrictions on gallium and germanium, two critical rare metals essential for semiconductor manufacturing, directly impacting U.S. and European producers (Rhodium Group, 2024). While these countermeasures created short-term leverage, China remained reliant on imports of EUV (Extreme Ultraviolet) lithography technology, necessitating their continued investment in lithography solutions, pushing to close the technological gap.

To further insulate itself from geopolitical risks, China adopted a multi-faceted industrial strategy that integrated workforce expansion, trade realignment, and supply chain redundancies. While technological independence and innovation remain core objectives, Chinese policymakers also prioritized the development of a highly skilled labor pipeline, recognizing that semiconductor self-sufficiency requires both infrastructure and talent.

A key component of this strategy involved the creation and expansion of state-sourced talent acquisition and retention programs, designed to counteract restrictions on foreign expertise and technology transfers while strengthening domestic R and D capabilities. Although this paper does not explore every facet of China's workforce strategy, several highlights illustrate the breadth of their approach:

Workforce Development and Talent Retention Initiatives

Rather than relying on foreign expertise, China scaled up internal talent recruitment programs to sustain semiconductor R and D. Key initiatives included:

- Qiming Program (est. 2018): Targeted high-caliber engineers with signing bonuses ranging from $420,000–$700,000 (approx. RMB 3–5 million) and housing subsidies in Shanghai and Shenzhen (Caixin, 2023).
- Thousand Talents Program and Kunpeng Plan: Recruited semiconductor specialists from overseas to backfill knowledge gaps created by U.S. visa and employment restrictions.
- Eastern Institute of Technology (EIT) Program: Focused on local, AI-integrated semiconductor expertise, ensuring the next generation of chip designers is trained within China's own academic ecosystem.
- Fast-Follower Strategies: China leverages trade partnerships with Japan, South Korea, and Taiwan's markets to acquire restricted technologies, mirroring industrial catch-up models seen in aerospace and telecommunications.

While these workforce investments allowed China to maintain short-term resilience, long-term success remained constrained by access to cutting-edge semiconductor manufacturing support equipment.

Stockpiling and Preemptive Equipment Acquisition Strategy

Recognizing the risk of prolonged U.S. trade restrictions, China began strategic stockpiling efforts as early as 2017. Between 2017 and 2022, China imported $93 billion worth of semiconductor manufacturing equipment, including DUV lithography machines and critical fabrication tools before additional U.S. sanctions could take effect (Yang and Potkin, 2024). This preemptive strategy was intended to:

1. Sustain maturing production capacity while China ramped up its indigenous semiconductor research.
2. Create a buffer period to develop homegrown EUV technology in Phase III of the Big Fund.
3. Reduce immediate dependence on Western suppliers, ensuring continued chip manufacturing for strategic sectors such as AI, defense, and telecommunications.

While these stockpiling efforts delayed severe supply chain disruptions, they failed to eliminate reliance on ASML's EUV lithography systems, a bottleneck that continues to limit China's ability to produce advanced-node semiconductors below 7nm. During the focus on manufacturing excellence, stockpiling gained a temporary edge against supply chain shocks. However, as the broader impact of export controls reverberated through China's semiconductor supply chain, pressure applied to key players encouraged Chinese leadership began to take notice.

Mounting Pressures on Tech Leaders

The tightening of U.S. semiconductor restrictions in 2022, building upon Trump-era 2019 export controls, triggered immediate industry-wide disruptions within China (BIS, 2022). The combined effects of supplier fragmentation, workforce losses, and talent migration constraints resulted in project delays, factory shutdowns, and major financial losses across key Chinese semiconductor firms (Cao and Pan, 2023).

Key Economic Disruptions:

- Wuhan Hongxin Semiconductor Manufacturing Co. (HSMC): Collapsed in late 2019 after $20 billion in mismanaged investments, marking one of the most severe financial failures in China's semiconductor history.
- SMIC's $7.6 billion Lingang Plant: Announced indefinite delays in early 2023, citing "uncertain market conditions" following U.S. export restrictions.
- YMTC Workforce Reduction: China's leading NAND flash memory producer laid off 10% of its workforce in 2023, directly attributing job losses to tightened U.S. trade policies.

Despite these setbacks, China avoided full stagnation, quickly recalibrating funding priorities and strategic investments through the re-imagined, Big Fund 3.0.

Despite overall success, China's semiconductor journey has not been without significant challenges. The path to technological self-sufficiency has been marked by institutional complexities, management issues, and the need for continuous strategic recalibration.

Visible disruptions and significant setbacks necessitated not just technical and financial adjustments but a fundamental reorganization of leadership and governance mechanisms, prompting the overhaul introduced in Big Fund 3.0.

Strategic Overhaul and Institutional Challenges

China’s Semiconductor Investment Evolution

As China’s semiconductor sector absorbed mounting external pressures, the government restructured its financial and governance frameworks to accelerate self-sufficiency. Under Big Fund 3.0 guidance, leadership transitioned to Zhang Xin, who shifted investment priorities toward long-term R&D in lithography and AI-integrated semiconductor manufacturing (Caixin, 2024; Min and Wei, 2024).

This evolution marked a response to several systemic challenges encountered in earlier phases:

1. Corruption and Mismanagement: Investigations by the Central Commission for Discipline Inspection (CCDI) revealed significant resource misallocation under former Big Fund President Ding Wenwu. The collapse of HSMC, despite $20 billion in allocated investments, reinforced the need for stricter oversight (Lee, 2024).
2. Over-Investment in Fabrication Without Equipment Support: Despite major financial commitments—RMB 55 billion to wafer fabrication, RMB 18 billion to IC design, and RMB 13 billion to ATP—only RMB 500 million was allocated to equipment development in Phase II. This skewed prioritization perpetuated reliance on foreign photolithography and etching tools, delaying China’s ability to domestically produce advanced semiconductors (CSC Financial, cited in Caixin, 2022).
3. Regional Disparities in Investment: Coastal hubs like Shanghai and Shenzhen absorbed most semiconductor funding, while inland cities such as Xi’an and Wuhan remained underdeveloped. Phase III aims to redistribute resources more equitably to sustain industrial expansion.
4. Overreliance on Legacy Technologies: Continued dependence on DUV lithography technologies restricted China’s ability to manufacture sub-7nm chips (e.g., sub-7nm). Although SMIC has refined 7nm production, bottlenecks remain, pushing Big Fund 3.0 to prioritize EUV research and AI-driven semiconductor advancements.

The strategic realignment under Zhang Xin reflects a shift from short-term industrial scaling to long-term systemic autonomy. Yet, success depends on sustained implementation of these corrective measures and the ability to adapt amid ongoing export controls and technological bottlenecks.

Despite these challenges, China's semiconductor sector continues to evolve rapidly, as seen in the emergence of Deep Seek R1 in late January 2025, a commercially available RAG model (and AI image generator) and the expansion of firms like Lonten Semiconductor. These developments suggest a resilient industrial strategy, even amid external restrictions and market instability (Priyadarshi, 2025; Lonten Semiconductor Financial Report, 2024).

After consideration of Chinese influence and expansion, the following summary has been developed to quickly reference and understand the implications and outcomes since developing US export controls on China.

To fully understand how advancements like Deep Seek R1 and Lonten Semiconductor reflect China's broader response to export controls, the following STORM framework dissects the multifaceted strategies driving China's iterative semiconductor supply chain expansion. These strategies span talent, technology, organization, regulation, and markets, with talent development being particularly pivotal. China has strategically targeted local labor pools by optimizing its educational ecosystem and steering workforce training to align seamlessly with the semiconductor industry's growing demands. Through initiatives like the Qiming Plan, Thousand Talents Program, and the Eastern Institute of Technology's Semiconductor Engineering Academy, China has scaled up domestic expertise, producing over 12,000 microelectronics graduates annually by 2025 and offering incentives like $420,000–$700,000 signing bonuses to attract high-caliber engineers. This tailored approach has efficiently addressed unmet skill demands, transforming past labor shortages—exacerbated by 2021–2022 corruption scandals that disrupted investment—into a robust talent pipeline that fits the industry's expansion like a glove, ensuring resilience and strategic alignment with national technological goals.

Below is a framework that examines Chinese industrial policy across a broad spectrum, assessing not only direct financial investments but also the social, technical, organizational, regulatory, and market-driven mechanisms that shape its strategic response to U.S. export controls.

The STORM Framework (Social, Technical, Organizational, Regulatory, Market Conditions) provides a structured analysis of China's adaptation, capturing both immediate responses and long-term strategic shifts in the semiconductor industry.

STORM Framework: China's Semiconductor Adaptation Strategy

This section applies the STORM framework—Social, Technical, Organizational, Regulatory, and Market conditions—to evaluate China's semiconductor strategy under sustained U.S. export controls. Each component is analyzed using a triangulated methodology that integrates: (1) policy announcements or state-led initiatives; (2) analytical reporting or scholarly assessment; and (3) independent verification through metrics, datasets, or registries. This layered approach ensures not only descriptive rigor but also analytical reproducibility.

S – Social Conditions: Talent Acquisition and Workforce Development (social dimensions of adaptation)

Facing persistent knowledge transfer restrictions, China has prioritized domestic talent pipelines. Major initiatives include:

- Policy Initiatives: The Qiming Plan (2025) expanded to include the Torch, Ruijin, and Yangtze River Scholars programs, offering $420,000–$700,000 (approx. RMB 3–5 million) signing bonuses and matching PhD-level researchers with industry R and D needs (China Talents Plan, 2025).
- Incentive Structure: The Thousand Talents Plan offers over $1M in annual salaries plus equity stakes in state-backed firms like SMIC (Lewis, 2023, Nature).
- Educational Ecosystem: The Eastern Institute of Technology (EIT), partnered with Huawei and Tsinghua University, launched a Semiconductor Engineering Academy to cultivate local design expertise.

Enrollment data from China's Ministry of Education (2025) reports a 15% increase in microelectronics graduates since 2023, producing over 12,000 engineers annually—empirically supporting Qiming's talent pipeline goals and the incentive structures documented by Lewis.

T – Technical Conditions: Infrastructure and Indigenous Innovation

China's technical advancements are centered around indigenous alternatives to restricted technologies:

- DUV Lithography: SMIC refined 7nm production using domestic DUV equipment, reaching performance levels comparable to TSMC's 2019 yields (Sohail, 2025).
- EUV Development: Huawei and SMIC began testing early-stage EUV systems, with production trials slated for mid-2025 and scale-up in 2026 (Lovati, 2025).
- Silicon Photonics: Investments in third-generation materials aim to boost AI efficiency, with experimental deployment in domestic chipsets (Priyadarshi, 2025).

CNIPA (2025) recorded a 40% year-over-year increase in lithography-related patents by SMIC, totaling 320 filings in 2024—corroborating media claims with verifiable R and D outputs.

O – Organizational Conditions: Strategic Stockpiling and Retaliation

Organizational responses reflect China's preemptive risk-mitigation and leverage-seeking behavior:

- Stockpiling Strategy: Between 2017 and 2022, China imported $93 billion in semiconductor manufacturing equipment, including DUV tools from ASML (Yang and Potkin, 2024).
- Retaliatory Measures: In 2024, China restricted exports of antimony—critical to aerospace alloys—causing global prices to jump from $22,000 to over $39,500 per ton (Reuters, 2024).
- Corporate Resilience: Firms like Huawei have doubled 7nm and 14nm chip reserves since 2022, securing a three-year production buffer (Min and Wei, 2024).

Trade data from China's General Administration of Customs (2025) confirms a $25 billion spike in DUV equipment imports from 2021–2023, aligning with firm-level stockpiling strategies and export restriction impacts.

R – Regulatory Conditions: Big Fund 3.0 and Governance Reforms

China's regulatory evolution emphasizes fiscal discipline and decentralized oversight:

- Governance Shift: Big Fund 3.0, launched in 2024 with $47.5 billion, introduces performance-based disbursements and ecosystem-driven funding to curb corruption (Baark and Qian, 2025).
- Investment Focus: 40% of the fund targets domestic lithography and third-gen semiconductors to bridge the sub-5nm gap by 2028 (Wang and Chen, 2025).
- Regional Equity: Up to 25% of funding is earmarked for inland provinces (e.g., Sichuan, Shaanxi), addressing prior overconcentration in coastal cities (CSIS, 2021).

While Caixin (2024) and Min and Wei (2024) report Zhang Xin as leading Big Fund 3.0, no official designation appears in SASAC or MIIT bulletins. Therefore, leadership attribution is treated as press-inferred rather than officially documented. However, SASAC reports confirm fund allocations and sectoral priorities.

M – Market Conditions: Net Gains vs. Losses from Export Controls

Despite initial shocks, China's semiconductor market reflects partial recovery and redirection:

- Domestic Growth: Output from key industrial zones (Shanghai, Xi'an) is expected to rise 25% between 2023–2025, powered by SMIC's expanding 7nm product line (TechInsights, 2022; WSTS, 2023).
- Export Expansion: Legacy chip exports are projected to increase 15% by 2025, driven by excess capacity and global demand for mature nodes (IDC, 2022; SIA, 2022).
- U.S. Firm Losses: NVIDIA and AMD face steep declines in China-based revenues due to export restrictions on AI chips (Reuters, 2023).

SEMI (2025) projects $187B in memory chip revenues (+24% YoY) and $156B from AI-related semiconductors (20% of the global market), confirming China's strategic positioning in high-growth sectors and validating its export pivot.

Please see the table below that explains the methodology behind the STORM analysis sourcing:

Table of Source Triangulation – STORM Analysis

STORM Element	Source 1 (Policy/Official)	Source 2 (Analytical)	Source 3 (Independent Metric)
Social	China Talents Plan (2025)	Lewis (2023, *Nature*)	Ministry of Education stats
Technical	Sohail (2025)	Lovati (2025)	CNIPA patent filings
Organizational	Min & Wei (2024)	Reuters (2024)	Customs trade data
Regulatory	SASAC investment reports	Baark & Qian (2025)	Caixin/Min & Wei (press) ★
Market	TechInsights/WSTS	Reuters (2023)	SEMI market forecast (2025)

> ★ Denotes inferred leadership, not directly confirmed by SASAC/MIIT.

Empirical Statistics: What do they show us?

Figure 5 below charts monthly integrated circuit exports to China from key suppliers—Japan, the Netherlands, and the United States—highlighting both enforcement variance and China's shifting sourcing strategies post-2023. Despite tightened controls, U.S. export volume shows a marked increase, while Japanese exports have declined—signaling different national responses and potential loopholes or licensing strategies.

This figure serves as an empirical baseline for understanding trade flow adaptation, particularly in the absence of direct firm-level or end-use data.

Methodological Notes**:**
-HS Code used: 854231 (Integrated Circuits)
-Y-Axis Clarification: Values are listed in **USD thousands** (e.g., 1,000 = $1 million). This -scaling follows standard customs reporting practice but may compress visual perception.
-Scoping Justification: The figure highlights Japan, the Netherlands, and the U.S.—each representing high-volume exporters to China with varying exposure to U.S. export control regimes.
-Data Sources**:**

– Taiwan data sourced from Customs Portal
– Additional data compiled from publicly available trade databases: U.S. Census Bureau, Eurostat, Japan Customs.

(Citations will be added in the full reference list.)

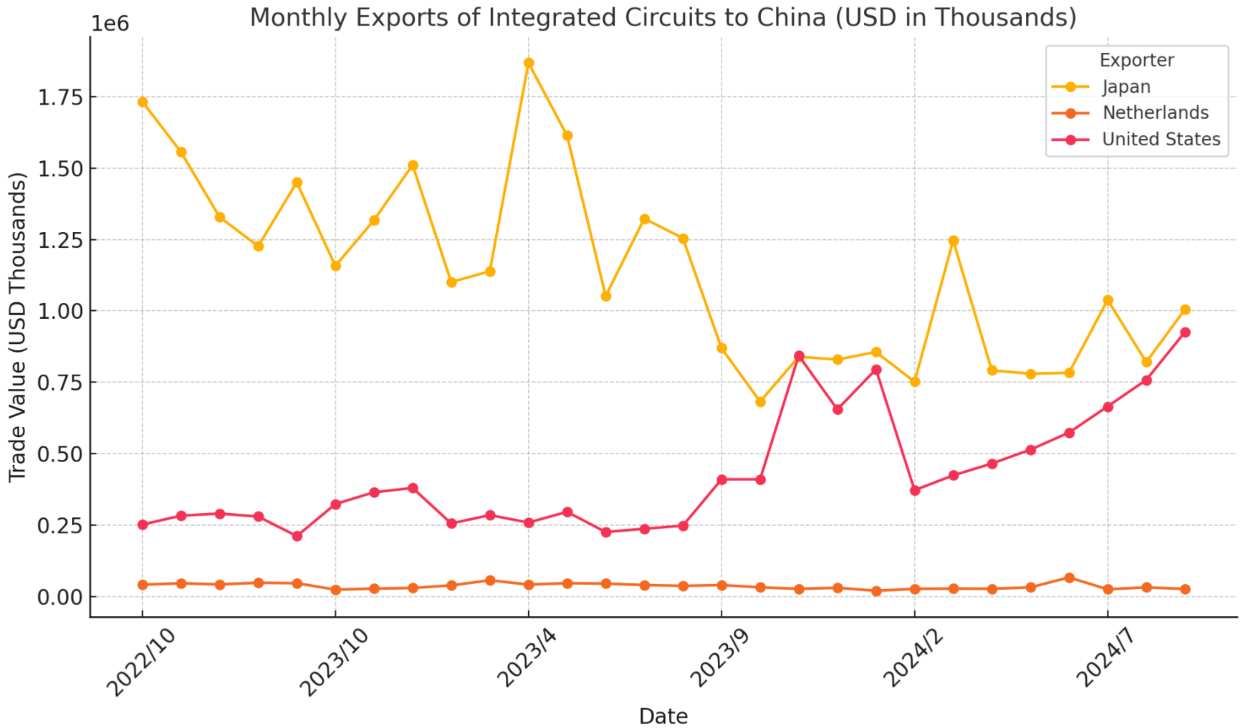


Figure 5.
Monthly exports of integrated circuits to China (USD Thousands), 2022–2024. Data highlight diverging national export trends post-2023: U.S. shipments rose despite restrictions, while Japan's declined. This reflects both enforcement asymmetries and China's evolving sourcing strategy.

Policy Recommendations for the U.S.

Given the findings from the historical and strategic analyses, it is evident that current U.S. strategies need significant strengthening. Export controls alone have proven insufficient in containing China's semiconductor ambitions, necessitating a more proactive, nuanced, and comprehensive policy approach. The following recommendations outline strategic areas for immediate U.S. action:

1. Forge Strategic Alliances:
   - Strengthen semiconductor partnerships with key global players including Japan, Taiwan, and the European Union to enhance supply chain robustness and preserve technological leadership. Leveraging the existing structure of the Wassenaar Arrangement, establish joint R and D task forces with semiconductor

infrastructure leaders such as TSMC and ASML to accelerate next-generation lithography and quantum computing technologies by 2027. Additionally, expand collaboration to secure critical materials like rare earth elements, safeguarding supply chains from disruptions and countering China's advancements in quantum computing and resource control.

2. Extend NSF-Led R and D Investments:
    - Increase investments through the National Science Foundation (NSF) and Defense Advanced Research Projects Agency (DARPA), proposing a dedicated $50 billion fund over five years specifically aimed at breakthroughs in extreme ultraviolet (EUV) lithography, AI-driven computational efficiency, and quantum computing. Enhance the existing NSF AI network, particularly the Institute for Advances in Optimization (AI4OPT), to include comprehensive graduate fellowships and STEM outreach initiatives at the elementary level, cultivating early interest and building a robust talent pipeline aligned with NSF's Smart and Connected Communities (S and CC) initiative.
3. Refine Export Control Strategies:
    - Transition from broad, sweeping export controls to precise, targeted restrictions focused explicitly on critical technologies such as EUV lithography systems, advanced AI chips, and quantum computing components. Establish a $10 billion support fund under the Department of Commerce to mitigate economic impacts on U.S. firms, ensuring resilience and economic stability through transitions. Prioritize support for enterprises significantly impacted by export control policies to balance national security interests with commercial viability.

These recommendations represent practical and strategically necessary interventions designed to reinforce the United States' technological leadership. Rather than restricting innovation, these policies actively promote strength, collaborative advancement, and economic stability, essential in countering China's sophisticated integration of governmental and industrial strategies.

Conclusion

This analysis underscores that U.S.-China semiconductor competition transcends simple trade restrictions, functioning as a pivotal geopolitical chess match with far-reaching implications. The cumulative effect of these restrictions has not stalled China's progress, but rather spurred adaptation and long-term industrial recalibration and renewed technological creativity. Employing the STORM framework highlights the multifaceted consequences of these policies, spanning social, technical, organizational, regulatory, and market dynamics.

The semiconductor competition fundamentally reshapes global technological development, reinforcing the necessity of continuous innovation and targeted investment over restrictive measures alone. Future research should further explore sophisticated economic modeling techniques, such as the Gravity Model, to quantitatively assess semiconductor trade flows and provide deeper insight into the long-term effectiveness of strategic export controls. Such analysis will offer critical guidance as data availability improves, refining our understanding of global technological sovereignty and informing more effective, nuanced policy decisions. While this paper is primarily qualitative, it lays the groundwork for future economic modeling efforts. Applying trade elasticity estimates, input-output models, or the Gravity Model could help quantify export controls' long-run impact on trade flows and domestic R&D effectiveness.

The export data used in this study were retrieved from Taiwan’s Ministry of Finance trade statistics system, which publishes harmonized monthly records by commodity code and trading partner. These records are particularly valuable for monitoring trends in high-tech trade and compliance behaviors across Asia-Pacific jurisdictions.
For consistency, this study focused on HS Code 8542 (Electronic Integrated Circuits) and extracted export data from Japan, the United States, and the Netherlands to China from September 2022 to December 2024 (preliminary).

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