Abstract: Export Controls and Their Unintended Effects on Global Innovation

Export controls are intended to limit adversarial technological progress but frequently yield unintended consequences, ultimately reshaping the technical landscape rather than halting it. The January 2025 Deep Seek R1 market correction shocked the AI supply chain, forcing industry-wide shifts in the design and outcome of computational efficiency. Restrictions on high-performance semiconductors, meant to curb China's AI capabilities, instead allowed advancements in supply chain innovation—demonstrating how regulatory barriers often drive unexpected technological breakthroughs (Allen, 2024). This paper examines a critical question: Are export controls slowing adversarial technical progress, or are they channeling adaptation and replotting its trajectory? Through multiple case studies and analysis of regulatory frameworks, this paper will demonstrate how export restrictions create unintended consequences, testing the traditional assumptions about their effectiveness.

This unpredictability manifests across multiple dimensions of China's strategic response. Since 2022, China has aggressively reengineered its developing semiconductor supply chains, recently allocating another funding injection (Priyadarshi, 2025) to kick off Phase III of the Big Fund. This latest cash injection to Chinas semiconductor national hedge fund, focuses on expanding domestic manufacturing and advancing lithographic R&D to eliminate foreign dependencies. Chinas inability to produce complex lithography machines, vital to cutting-edge production standards, is considered an Achilles heel and primary roadblock to self-sufficiency. China's shift toward scaled manufacturing, including their magnitude and range of manufacturing precision, are direct effects of Chinese supply chain crisis management, planned intervention, and expert-level guidance. The sum of China's outstretched endeavors reflects their broader interest of reducing reliance on U.S. and other Western chipmakers. China's strategic initiative extends beyond manufacturing into comprehensive countermeasures, including investments in disruptive technologies like undersea cable-cutting and seabed data center storage capabilities, which could threaten global supply chains. Under the third iteration of the Big Fund 3.0, projections are extended to 15 years (2024–2039) and are supported by an enhanced project governance structure (Lee, 2024). This structured policy shift underscores how export controls may accelerate—rather than stall—a competitor's path to technological self-sufficiency.

Introduction:

This paper examines the uncertainty and effectiveness of export controls, assessing their impact on China's labor and supply chain restructuring, financial realignments, and geopolitical strategy. Through case studies such as the Deep Seek R1 market correction on January 27, 2025, this research highlights how export restrictions can trigger unintended technological advancements and externalities, forcing adaptation rather than stagnation. By restricting China's access to high-performance semiconductors, U.S. policies inadvertently accelerated innovation in computational efficiency, reinforcing the unpredictable nature of regulatory intervention.

Beyond immediate consequences such as bankruptcies, layoffs, and supply chain disruptions, this analysis seeks to establish a quantifiable framework for assessing export control effectiveness. While policymakers intend to suppress adversarial technological progress, the strategic outcomes remain difficult to measure. Can export restrictions be assessed through economic modeling, or do they merely shift the trajectory of innovation? To what extent do they delay progress rather than prevent it? By introducing a structured evaluation of economic disruptions and secondary market effects, this research provides a foundation for understanding the externalities that emerge from regulatory containment strategies. This paper serves as a guidepost for exploring the pathways and methods of measurement of economic impacts by export controls.

The January 2025 Deep Seek R1 disruption serves as a timestamped demonstration of export control unpredictability. It exemplifies how export controls, despite their intent to limit strategic competitors, can set off a chain reaction of unintended consequences—forcing innovation, reshaping supply chains, and uncovering hidden adaptation pathways. This reflects the broader challenge of export control policy—once enacted, its full consequences remain uncertain and irreversible. The true economic impact of export controls lies not only in immediate disruptions but also in the unseen, long-term externalities that shape global markets and technological ecosystems.

China's workforce realignment is just one adaptation to export restrictions. However, the effectiveness of these restrictions is also shaped by the international regulatory framework—most notably, the Wassenaar Arrangement, which governs the transfer of sensitive technologies. Established in 1996 to replace the Cold War-era Coordinating Committee for Multilateral Export Controls (COCOM), Wassenaar introduced a decentralized, multilateral framework for regulating strategic technologies. With 42 member states, including Russia, the Wassenaar Agreement operates on a consensus-driven model, meaning nations interpret and enforce restrictions at varying levels of stringency. Unlike its predecessor, which explicitly targeted Soviet-aligned adversaries, Wassenaar's scope includes dual-use technology limitations, categorized under the Munitions List (ML) for conventional weapons and the Dual-Use List (DL) for sensitive commercial technologies (Grimmett, 1996). However, this structure has created enforcement asymmetries, as some member states maintain less restrictive policies, creating gaps that China and other strategic competitors may exploit.

At the core of China's strategic response is an optimized talent pipeline. Through a three-layered approach—aggressive domestic recruitment (TTP), targeted international poaching (Qiming), and state-backed academic expansion—Beijing has established a comprehensive workforce strategy directed at semiconductor fabrication and AI capabilities. The ecosystem is championed by key research hubs including the Eastern Institute of Technology (EIT), its affiliate the Eastern Institute of Advanced Study (EIAS), and the Ningbo Oriental University of Science and Technology (Eads, Clarke, Kaesar, & McCreight, 2023), all receiving direct government support to maintain high-output research and training. This coordinated human capital development further illustrates how export controls can trigger sophisticated nation-state level responses that extend beyond intended technological boundaries.

In contrast to China's state-backed labor and research initiatives, the U.S. has pursued a more rigid, institutional approach through programs such as the AI Institute for Advances in Optimization (AI4OPT). By using CHIPs Act funding, this program was curated by the National Science Foundation (NSF Award Abstract #2112533) and prioritizes decision-based AI, industrial automation, and infrastructure resilience. While AI4OPT focuses on optimization and logistics, China has pursued a state-directed AI mobilization strategy since 2014, leveraging their recently expanding workforce pipelines, doubling down on state-subsidized R&D, and taking a militarized approach to AI governance. This highly coordinated recruitment and training phase, combined with centralized control over AI-driven behavioral data, places China in a position of strategic counteroffensive in AI research and future workforce application, signaling their aggressive intentions of dominance over the digital landscape.

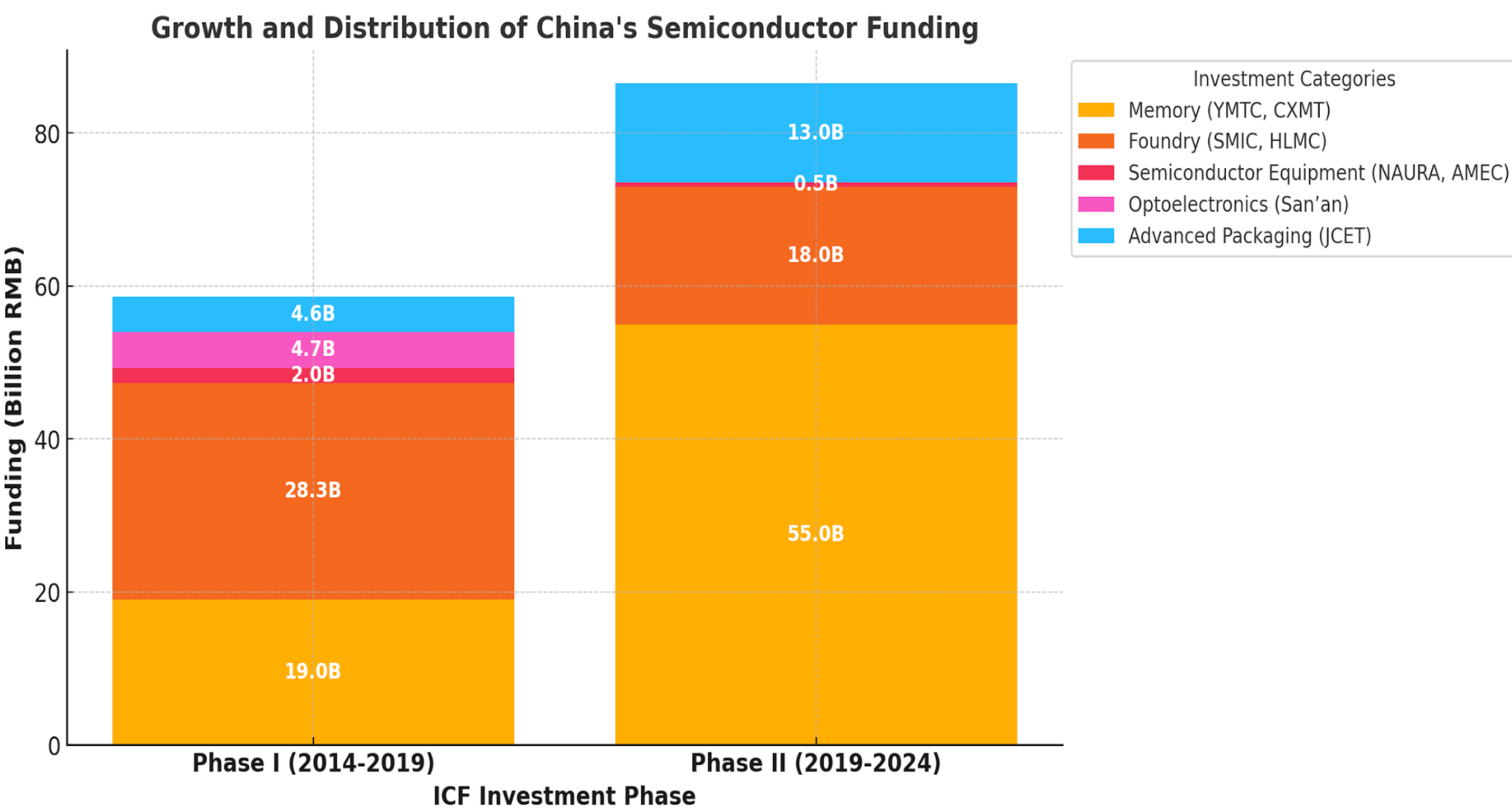
Beyond economic and security factors, export controls shape AI's ethical landscape in three key areas. First, they attempt to limit adversarial AI weaponization—such as cognitive warfare and misinformation algorithms. Second, they raise concerns over algorithmic governance, as restrictions may unintentionally drive more invasive state-run AI initiatives. Lastly, policymakers face a dilemma: How can AI export controls curb authoritarian misuse without stifling beneficial AI innovation? The rise of deep-learning behavioral modeling, predictive habit analysis, and AI-enhanced cognitive warfare has fundamentally altered how adversaries' approach and direct influence, manipulating global information flows. These capabilities, when weaponized for misinformation campaigns, psychological operations, or surveillance-state expansion, present new threats that traditional security policies struggle to address. While export controls attempt to limit adversarial access to these technologies, the growing sophistication of China's AI sector raises urgent concerns regarding the future of civil liberties, digital ethics, and algorithmic decision-making.

Modern Applications and Challenges – Crowdfunding the Chinese Circuit Supply Chain
The largest hurdle China planned to overcome was funding and disbursement. Efficient funding permitted the fabrication of integrated circuits and modern lithography tooling to the homeland in a concentrated push for supply chain independence. Due to an expansion of computer network operations and ambitions, the Chinese Communist Party (CCP) initiated a funding effort named The Big Fund. In 2014, the Central Bank established a low-profile fund focused on developing modern supply chain solutions, creating a timeline for China to catch up in the manufacture of integrated circuits (Tao, 2018). These initial funding efforts laid the groundwork for a more structured approach, evolving into a pivotal mechanism for China's technological ambitions. This shift marked the formal establishment of a key initiative to drive semiconductor self-sufficiency.

Evolution and Impact of China's Integrated Circuit Industry Investment Fund (ICF)
The establishment of China's Integrated Circuit Fund (ICF), or, the "Big Fund," marked a defining chapter in the country's ambition to achieve technical sovereignty. Launched on September 26, 2014, by the Ministry of Industry and Information Technology (MIIT), the fund was designed to "invest in chip manufacturing, boost industrial production, and promote mergers

and acquisitions" (Caixin, 2022). Operating under the joint oversight of MIIT and the Ministry of Finance, the fund's phased development has driven China's semiconductor industry through periods of significant growth, extreme volatility, and strategic realignment. The ICF's progress over three phases reveals not only its transformative impact but also highlights the iterative lessons learned from early oversights. This crowdfunded evolution began with Phase I, prioritizing foundational investments.

[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.]



Phase I: Laying the Foundation (2014-2019)

The first phase of the ICF, with a total raised capital of 138.72 billion yuan ($21.8 billion), prioritized foundational investments to expedite China's semiconductor capabilities. A remarkable 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).

Below: Table shows 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.

Despite notable allocations, only RMB 2 billion—a mere 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. Efforts supporting China's self-reliance and decreasing dependence on imported lithography tools from ASML and other foreign suppliers continued to lag, limiting China's ability to produce chips 7nm or below.

Another setback affecting project delivery was the failure of several facilities. The HSMC scandal, often referred to as the "Semiconductor Theranos," was characterized by large-scale financial mismanagement, with significant public funds lost and unrecovered. Reports surfaced detailing that construction was virtually halted at a major government-backed firm in Wuhan. The building was to house China's first 7-nanometer (nm) chip fabrication plant in a 650,000 square meter (around 160-acre) structure. Reports emerged that the site had been idle since December 2019. The well documented failure of the HSMC plant cut deep into China's plan to supply 70 percent of its chip demand by 2025 (Sheng, 2020).

Overall, Phase I investments succeeded in catalyzing industry-wide growth, driving a surge of private capital into the sector. Between 2015 and 2019, the fund leveraged an additional 500 billion RMB in private investments, amplifying its impact across the semiconductor ecosystem. By supporting capacity expansion, such as YMTC's memory production and SMIC's foundry operations, the fund laid the groundwork for China's ambitions to become a global semiconductor powerhouse. However, its narrow focus on manufacturing at the expense of upstream R&D and equipment development limited the scope of its early achievements (Caixin, 2022). Building on these early successes, the fund entered a more ambitious phase to scale production and address emerging challenges. This evolution reflected China's growing determination to overcome initial limitations.

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), represented a significant expansion in scale and ambition. This phase shifted its focus toward scaling wafer fabrication capabilities, with 75% of funds—approximately RMB 55 billion—allocated to this segment (CSC Financial, cited in Caixin, 2022). Notable aspects of Phase II include:

- **Wafer Fabrication Dominance:** Investments in large-scale production facilities aimed to address the capital-intensive nature of semiconductor manufacturing. SMIC and other leading foundries expanded their capacity to produce 14nm and 28nm nodes, albeit with limitations in advanced process nodes due to restricted access to EUV (extreme ultraviolet) lithography equipment (Liang, 2024).
- **Design and ATP:** RMB 18 billion was allocated to IC design companies, while RMB 13 billion supported assembly, test, and packaging. These investments reinforced China's midstream and downstream capabilities, helping firms like JCET expand their global competitiveness in ATP (Caixin, 2022).
- **Equipment Development Gap:** Despite its scale, Phase II allocated only RMB 500 million to equipment development. This underinvestment perpetuated China's dependence on foreign suppliers for critical technologies like photolithography and etching tools. The reliance on deep ultraviolet (DUV) lithography—a legacy technology—remains a significant constraint as SMIC struggles to achieve advanced nodes such as 5nm and beyond (Caixin, 2022).

In addition to direct investments, Phase II successfully mobilized an estimated RMB 600 billion in private capital, exceeding Phase I's leverage. This achievement underscores the fund's ability to align state and market resources to pursue national strategic goals. However, regional disparities in fund allocation began to emerge, with coastal areas like the Pearl River Delta benefiting disproportionately while inland provinces lagged. For instance, Guangdong's electronics and telecom industry, centered in the Pearl River Delta, contributed RMB 4.67 trillion (US$642.25 billion) in revenue in 2022, accounting for 26 percent of the province’s industrial revenue. In contrast, central and western regions, including cities like Wuhan, Xi’an, and Chengdu, are rapidly developing their integrated circuit and semiconductor industries but have yet to reach the same level of economic contribution.

While Phase II marked a period of aggressive semiconductor scaling, inefficiencies in funding allocation, continued dependence on foreign suppliers, and leadership instability highlighted the need for a more structured approach. These challenges prompted the shift to Phase III under the broader, renewed Big Fund 3.0 initiative. Chinese leadership reorganization suggests a cohesive and strategic realignment focused on vertical integration, domestic R&D, and governance reform. Despite these internal advancements, U.S. export controls in 2022 tested China’s progress.

Mounting Pressures on Tech Leaders

Before China’s expansive, resilient, and recession-hardened supply chain took shape, early guidance from the Ministry of Industry and Information Technology (MIIT) provided the foundational structure for a self-sufficient semiconductor ecosystem. However, the Biden administration’s export controls, introduced in October 2022, triggered immediate disruptions in recruitment and operations (BIS, 2022). Within months, companies dependent on foreign talent and suppliers struggled to maintain production continuity. Chinese dual citizens working for both American and Chinese companies were forced to sever ties with their home nation, creating a sudden and critical knowledge gap in the sector.

By early 2023, less than six months after the U.S. tightened export controls, China’s semiconductor industry suffered notable setbacks. Stalled manufacturing facility activations, widespread layoffs, and supply chain distortions led to decreased overall industry performance. One of the first major industrial casualties was the collapse of Hongxin Semiconductor Manufacturing Company (HSMC) in Wuhan, highlighting the fragility of China’s semiconductor expansion efforts. Shortly after, in February 2023, the Semiconductor Manufacturing International Corporation (SMIC) announced significant delays in its $7.6 billion Lingang, Shanghai plant due to "uncertain market conditions" driven by U.S. export restrictions (Cao & Pan, 2023). Similarly, Yangtze Memory Technologies Corporation (YMTC) was forced to lay off approximately 10% of its workforce in early 2023 due to escalating restrictions (Cao & Pan, 2023). These failures underscored a crucial reality—China's semiconductor ambitions, shaped by the Made in China 2025 industrial policy, could not afford setbacks. **These disruptions forced adaptation, not stagnation,** echoing the unintended consequences highlighted by the Deep Seek R1 case, as China sought to navigate these external pressures (page 5). Central to this adaptive response was strong leadership, with figures like Xiao Yaqing playing a critical role in steering the industry forward. His strategic vision became a cornerstone of China’s resilience strategy.

Xiao Yaqing and China’s Semiconductor Strategy

Xiao Yaqing, a pivotal figure in China’s semiconductor strategy, played a significant role in the CCP, serving in the Central Commission for Discipline Inspection (CCDI) from 2012 to 2017. As the CCP’s primary anti-corruption body, the CCDI enforced party discipline, financial oversight, and investigations. Within China’s semiconductor sector, this oversight became critical as the government pursued aggressive funding and self-sufficiency policies in response to U.S. export controls.

During his tenure, Xiao championed the establishment of a centralized investment fund that functioned as a quasi-central bank for China's semiconductor supply chain. With a target of achieving self-sufficiency by 2030, this initiative became known as the Big Fund (正式名称：国家集成略投基金)—represented China’s strategic push for technological independence. Under Xiao’s leadership, China implemented specific strategies to counter these controls, focusing on stockpiling and retaliation to secure its supply chain. These measures marked a decisive shift toward long-term self-reliance.

Stockpiling and Strategic Retaliation: Securing China’s Semiconductor Supply Chain

When U.S. export restrictions targeted China’s established trade and technology access points, a bullwhipping effect triggered an amplified surge in demand for restricted technologies. This environment compelled leading firms like Huawei to preemptively stockpile critical semiconductor components (Creemer & Papagianneas, 2024). Recognizing the long-term risks posed by these measures, Xiao Yanqing directed a multi-layered strategy to secure China’s semiconductor supply chain. Under his leadership Xiao’s strategy encompassed multiple fronts:

• Between 2017 and 2022, China imported $93 billion worth of semiconductor manufacturing equipment (SME), preemptively countering potential supply chain disruptions (Yang & Potkin, 2024).

• Chinese buyers acquired large volumes of SME as foreign acquisitions became increasingly difficult.

• Huawei launched long-term semiconductor stockpiling initiatives designed to insulate production from immediate shocks.

• China imposed retaliatory export restrictions on gallium and germanium, thereby exposing vulnerabilities in U.S. and European supply chains (Rhodium Group, 2024).

• Significant investments in legacy chip production for electric vehicles (EVs) ensured stability in critical manufacturing sectors, reinforcing China’s competitive position in the automotive industry.

While these stockpiling measures provided an initial buffer, they were only part of Xiao's broader defensive strategy. Recognizing that a singular focus on hoarding materials was insufficient for long-term resilience, he also diversified internal supply chains. With backing from the Big Fund, companies like Huawei not only secured critical semiconductor stockpiles but also strategically invested in legacy chip production—efforts that have proved essential for mitigating bottlenecks and ensuring economic stability.

Simultaneously, as part of its strategic retaliation, China imposed further export restrictions on key inputs such as gallium and germanium in mid-2023. These calculated moves reinforced the nation's ability to absorb economic shocks while pressuring adversary supply chains (Rhodium Group, 2024). Beyond these measures, China aggressively expanded domestic lithography development—investing in industrial parks and clean room facilities—to reduce its reliance on foreign technologies like ASML's EUV systems (Lovati, 2025).

This comprehensive approach ultimately laid the foundation for long-term self-sufficiency. The efficacy of these measures was dramatically demonstrated in 2023 when Huawei released its Mate 60 Pro smartphone, featuring a domestically produced 7nm chip by SMIC—a milestone that underscored China's rapid technological advancement despite ongoing export controls, even as it still trails behind the most advanced nodes produced by TSMC and Samsung (Schleich & Reinsch, 2023).

Together, these coordinated actions under Xiao Yanqing's strategic direction highlight how orchestrated stockpiling, retaliatory trade measures, and targeted investments in both legacy and cutting-edge semiconductor technologies formed a robust defense against external economic pressures. This multi-pronged strategy not only provided immediate economic stability but also paved the way for China's gradual march toward technological self-reliance.

[Briefly talk about leader zheng replacing Ding Wengu (https://www.taipeitimes.com/News/biz/archives/2023/03/14/2003796048) (prob not needed)

Navigating Export Controls: What Worked – China's Strategic Semiconductor Shift

China's Response: Talent Acquisition and Strategic Academic Investment

Recognizing the immediate impact of export controls, China's technology leadership responded with aggressive countermeasures. A key focus was workforce development, an area heavily impacted by restrictions on knowledge transfer and collaborations with Western experts. The Qiming Program, launched in 2018, became one of China's primary tools for attracting PhD-level expertise in semiconductor engineering. Through a combination of financial and career incentives, the initiative aimed to offset the talent drain caused by U.S. restrictions. The program included:

- Signing bonuses: \$420,000 - \$700,000 per recruit (Caixin, 2023).

- Housing subsidies: Fully covered in tech hubs like Shanghai and Shenzhen.
- Long-term compensation: Equivalent to senior executive packages for mid-career transitions. China also expanded recruitment through the rebranded Thousand Talents Program (TTP), Kunpeng Plan, and the Eastern Institute of Technology (EIT) Program, actively drawing expertise from Taiwan, South Korea, and beyond. These efforts reinforced the country's semiconductor labor pipeline but still faced headwinds as restrictions tightened.

Unlocking Trade Partnerships: The Fast Follower Technique

China's ability to rapidly adapt to external constraints is perhaps best demonstrated through its application of the Fast Follower technique—a strategy designed to close technological gaps without being a first mover. Historically, China has leveraged strategic partnerships to accelerate technological advancements, forming alliances that enable the exchange of goods, services, and intellectual capital. By embedding itself in global supply chains and leveraging mutual dependencies, China has positioned itself to quickly adopt cutting-edge technology, reverse-engineer existing solutions, and integrate those learnings into its own industrial ecosystem.

Strategic Overhaul: China's Semiconductor Investment Evolution

Addressing Key Pressure Points: The Role of Leadership and Technology

Chinese leadership, driven by figures like Xiao Yaqing, identified critical pressure points in the nation's semiconductor strategy and addressed each challenge directly. Under Xiao's direction, the Integrated Circuit Fund focused on acquiring or replicating essential semiconductor manufacturing equipment. Despite these efforts, progress remained gradual; for instance, Semiconductor Manufacturing International Corporation (SMIC) achieved 7nm chip production using Deep Ultraviolet (DUV) lithography—a less advanced technology compared to Extreme Ultraviolet (EUV) lithography. This reliance on DUV allowed China to mitigate some impacts of U.S. export controls but highlighted ongoing challenges in accessing cutting-edge EUV technology. DUV lithography, while capable of producing advanced chips, often necessitates complex and time-consuming multi-patterning techniques, making it less efficient and potentially more costly than EUV lithography, which uses a shorter wavelength of light to enable smaller, more intricate chip designs (Middleton, 2024).

Big Fund 3.0: Leadership and Governance Shift

The removal of Xiao Yaqing in July 2022 due to corruption charges marked a turning point for China's semiconductor funding strategy. Following governance failures in Big Fund Phases I and II, China appointed Zhang Xin to lead Big Fund 3.0 in early 2024. Unlike previous leadership, Zhang's mandate emphasized regulatory oversight, efficiency-driven investment, and financial discipline to restore credibility and investor confidence in state-backed projects (Caixin, 2024). In early 2024, China announced Big Fund 3.0, allocating $47.5 billion to semiconductor development over a 15-year plan (2024-2039)—a shift from the five-year timelines of prior phases. This phase prioritizes infrastructure and lithography R&D, semiconductor manufacturing, AI-supportive hardware, and vertical integration, reflecting a strategic, long-term push for self-sufficiency (Min & Wei, 2024). The restructuring underscores China's recognition that unchecked capital allocation alone is insufficient, requiring resolved governance inefficiencies to address supply chain vulnerabilities (Lee, 2024).

Signs of Success and Challenges Ahead

The effectiveness of China's strategic shift is already visible. Since the launch of Deep Seek R1, a cutting-edge AI image generation model, reports highlight ICF-backed firms achieving breakthroughs despite U.S. restrictions. The rapid development of AI infrastructure to support Deep Seek's demand—enabled by Phase III's focus on lithography and AI integration—suggests export controls may have accelerated China's domestic innovation (Priyadarshi, 2025). Financial reports from Lonten Semiconductor corroborate this, showing government-backed firms expanding despite supply chain constraints, with its IPO prospectus underscoring sustained state support for sustainable semiconductor infrastructure (Lonten Semiconductor Financial Report, 2024). However, success is not guaranteed. Technological bottlenecks and geopolitical trade constraints persist, and if Zhang's governance reforms falter, Phase III could repeat past setbacks.

Implications for U.S. Technology Policy

The U.S. must now assess whether its export control strategy has achieved its goals or inadvertently hastened China's self-sufficiency. As China expands investments in semiconductors, AI, and talent, Washington faces an urgent challenge: shifting from reactive export restrictions to a proactive strategy—investing in domestic production, strengthening supply chains, and deepening allied partnerships—to maintain global leadership.

Systemic Challenges and Lessons from Past Phases

While the ICF's phased development has driven progress, it has exposed persistent challenges:

1. **Corruption and Mismanagement:** Investigations by the Central Commission for Discipline Inspection (CCDI) into key figures, including Ding Wenwu (former Big Fund President), revealed systemic mismanagement and resource misallocation. High-profile failures like Wuhan Hongxin Semiconductor Manufacturing Corporation (HSMC), which wasted billions on incomplete facilities, underscore the need for stronger oversight.

2. **Underinvestment in Equipment and Materials:** Phases I and II allocated only RMB 2 billion and RMB 500 million, respectively, to equipment development, leaving China reliant on foreign suppliers and delaying self-reliance.

3. **Regional Disparities:** Coastal regions like the Pearl River Delta have disproportionately benefited, risking broader innovation by underfunding central and western provinces.

4. **Overreliance on Legacy Technologies:** Continued reliance on DUV limits China's competitiveness at advanced nodes (e.g., 3nm, 2nm).

Strategic Impact of Export Controls on Global Trade

The ICF's evolution offers lessons for industrial policy, showcasing a blueprint for mobilizing capital while highlighting trade-offs between rapid expansion and sustainable innovation. A STORM analysis blending qualitative and quantitative methods reveals how export controls reshape trade dynamics, shifting demand and financial networks across semiconductor-producing nations. China's long-term success hinges on addressing structural weaknesses amid geopolitical challenges. As Phase III unfolds, its focus on vertical and subsea data network integration could redefine the global semiconductor landscape, positioning China as a forerunner and disrupting Western chip leaders' value streams.

STORM Analysis – Evaluating Export Controls

While the U.S. intended to curb China's semiconductor advancements, policy has had both anticipated and unintended consequences. The **Social, Technical, Organizational, Regulatory, and Market (STORM) framework** highlights the complexities of these impacts, revealing both vulnerabilities and unexpected innovation accelerations.

S – Social Conditions: Talent Acquisition and Workforce Development U.S. restrictions on knowledge transfer and collaborations forced China to accelerate domestic talent development. Programs such as the **Qiming Program (2018)** and **Kunpeng Plan** focused on targeted PhD recruitment, offering:

- **Signing bonuses:** $420,000 - $700,000 per recruit (Caixin, 2023).
- **Housing subsidies:** Fully covered in Shanghai and Shenzhen.

- **Executive-level compensation** for experienced engineers transitioning into China's semiconductor sector.

Additionally, the **Eastern Institute of Technology (EIT) Program** and **Thousand Talents Plan (TTP)** reinforced China's semiconductor labor pipeline. While these measures bolstered domestic R&D, restrictions on Chinese researchers abroad slowed progress in frontier innovation (Goujon & Reynolds, 2024).

T – Technical Conditions: Infrastructure and Indigenous Innovation Despite losing access to ASML's EUV lithography, China demonstrated resilience by advancing legacy semiconductor technology:

- **SMIC's 7nm chip production** using **DUV lithography**—a major workaround (Caixin, 2022).
- **Tsinghua University's memristor chip breakthrough (2023)** in non-volatile memory technology (Techovedas, 2024).
- **Huawei's Mate 60 Pro**, featuring an indigenous **5G modem**, circumvented U.S. restrictions (Min & Wei, 2024).

These developments highlight China's drive for self-sufficiency, though the **absence of EUV technology remains a bottleneck** for sub-5nm chip production.

O – Organizational Conditions: Strategic Stockpiling and Retaliation Between 2017 and 2022, China's stockpiling and retaliation (see pp. 8-9) buffered supply chain shocks.

Key measures included:

- **Huawei's long-term semiconductor stockpiling** for sustained production.
- **China's retaliatory restrictions on gallium and germanium exports**, affecting Western supply chains (Rhodium Group, 2024).
- **Investments in legacy chip production for EVs**, ensuring sector stability.

R – Regulatory Conditions: Big Fund 3.0 and Governance Reforms Phases I and II of the **Big Fund** catalyzed manufacturing growth but suffered from corruption and mismanagement. The leadership shift from **Ding Wenwu to Zhang Xin** signaled a restructuring:

- **Enhanced governance** to prevent financial mismanagement.
- **Increased investment** in lithography and semiconductor equipment manufacturing.
- **Strategic recalibration** to address high-end chip design challenges.

Despite these efforts, regulatory inconsistencies persist, with **coastal regions disproportionately benefiting** from fund allocations.

M – Market Conditions: Net Gains vs. Losses from Export Controls While U.S. restrictions disrupted China's semiconductor supply chains, they also forced innovation and spurred domestic investment:

- **China's stockpiling measures softened immediate damage**.
- **Western firms like NVIDIA lost revenue streams** due to restrictions on A800 and H800 chip sales to China (Cheng, 2024).
- **Investment in semiconductor industrial parks** expanded China's domestic chip production capacity.

China's resilience mitigated short-term losses, though its **long-term success hinges on securing EUV lithography and achieving sub-5nm chip production**.

Policy Recommendations

1. **Forge Strategic Alliances:** Enhance semiconductor collaborations with Japan, Taiwan, and the EU to strengthen supply chains and sustain U.S. technological leadership. Establish joint R&D task forces with TSMC and ASML to co-develop next-generation lithography by 2027, leveraging existing Wassenaar Arrangement ties.
2. **Extend NSF-Led R&D Investments:** Build on the National Science Foundation's AI Institute for Advances in Optimization (AI4OPT, NSF Award #2112533) by allocating $50 billion over five years to NSF and DARPA. Focus funding on EUV lithography breakthroughs and AI-driven computational efficiency, matching China's Big Fund 3.0 scale ($47.5 billion). Expand AI4OPT's scope to include semiconductor design optimization, targeting a 20% efficiency gain in 7nm-and-below nodes by 2030, countering China's DUV reliance.
3. **Refine Export Control Strategies:** Shift from broad restrictions to targeted controls on critical technologies (e.g., EUV equipment), minimizing collateral damage to U.S. firms like NVIDIA. Create a $10 billion support fund to offset losses for businesses impacted by supply chain shifts, ensuring resilience during policy transitions.

Export controls have, for better or worse, **reshaped China's technological trajectory**.
The **STORM framework** underscores the unpredictable consequences of policy, reinforcing the need for a **balanced, adaptive, and case-by-case approach**.

The U.S. must **execute its semiconductor strategy more effectively**, taking cues from China's ability to integrate business with government for industrial progress. Despite external constraints, China's semiconductor sector has **demonstrated resilience and adaptation**. The **Made in China 2025** strategy prioritizes biotech, energy, agriculture, finance, and technology—sectors the U.S. must actively compete in to sustain long-term leadership. **Strategic action is needed now** to maintain the U.S. edge in global technology and innovation.

Appendix i.

Market Conditions: Net Gain or Net Loss? Could Econometrics Paint a Better Picture?

The economic impact of export controls on the U.S. and China presents mixed results:
- Net Gain for China? There was always a net gain for China, so how much of a net gain have we enabled versus projected models? And what is the margin of their total damages minus the U.S total damages? ***How*** did ***we measure*** and was it repeatable/effective?
  - Forced innovation: Necessity has driven advancements in indigenous chip manufacturing. The next 15 years will be paramount to Chinese success via adherence to a synergized planning schedule.
  - Supply chain restructuring: Investment in industrial parks has increased self-sufficiency.
  - Stockpiling and adaptation: Companies like Huawei have demonstrated resilience and market control through supply chain diversification strategy.

- Net Loss for the U.S.?
  - Impact on U.S. firms: NVIDIA lost significant revenue streams due to restrictions on A800 and H800 chip sales to China (Cheng, 2024).
  - Long-term consequences: U.S. R&D investments in manufacturing are paced by China's rapid development in expansive talent sourcing and alternative technologies.
  - Sunk costs and productivity drain: The infrastructure built for export control enforcement may not yield intended strategic benefits (Priyadarshi, 2025).

Here are some measurement concepts:

1. The Gravity Model of Trade (For Trade Flow Disruption)

Equation:

$$X_{ij} = G \cdot \frac{GDP_i \cdot GDP_j}{D_{ij}^{\beta}}$$

Where:

- X_{ij} = Bilateral trade volume between country i and j.
- GDP_i, GDP_j = GDP of exporting and importing countries.
- D_{ij} = Distance between trade partners (proxy for trade barriers).
- β = Elasticity of trade to distance.
- G = Scaling constant.

Justifies how you measure trade impact

Runner up philosophies:

1. Trade Flow Loss Rate (TFLR)

$$TFLR = \frac{X_{\text{pre}} - X_{\text{post}}}{X_{\text{pre}}}$$

Where:

- X_{pre} = Total exports to China before restrictions.
- X_{post} = Total exports to China after restrictions.
- **Interpretation:** A positive $TFLR$ indicates a decline in exports, meaning effective restrictions. A negative $TFLR$ (unexpected) means increased exports despite controls.

2. Capital Flight Factor (CFF)

$$CFF = \frac{I_{\text{pre}} - I_{\text{post}}}{I_{\text{pre}}}$$

Where:

- I_{pre} = Foreign direct investment in China's semiconductor sector before controls.
- I_{post} = Investment after controls.
- **Interpretation:** A high CFF (close to 1) means significant capital outflows from China, indicating economic damage.

3. Demand Decay Function (Similar to Signal Loss in Networks)

$$D_t = D_0 \cdot e^{-\lambda t}$$

Where:

- D_0 = Initial semiconductor demand in China.
- λ = Demand loss rate (influenced by export restrictions, R&D lag, domestic substitution).
- t = Time since export controls took effect.
- **Interpretation:** Higher λ values indicate faster demand erosion, while a low λ suggests resilience.

Appendix ii.

RESERVED

Appendix iii. Technical Conditions: Infrastructure and Innovation Responses

okay thanks - now this 'Here is where you announce – 'this is why I have introduced my measurement methods and economic basis of understanding how export controls can shape global trade, exchanging demand from supplier to supplier, creating and cancelling lines of credit between the 4 nations tasked the heaviest, outfitting our world with the latest in algorithmic performance.

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