China's Critical Technology Surge: A Contested Ascent

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Executive Summary

This report examines China's remarkable ascent in frontier innovation across artificial intelligence, semiconductors, and quantum computing, demonstrating how the world's second-largest economy is rapidly closing the technological gap with the United States. While the US maintains overall leadership, China has achieved significant progress and even parity in key subfields of these three critical technologies. However, this ascent is contested and fraught with challenges. China's state-driven industrial policy, while effective in mobilizing resources, has also led to inefficiencies, waste, and a reliance on foreign technology in critical upstream segments, particularly in semiconductors. US-led export controls have created significant bottlenecks, forcing Chinese firms to innovate around constraints. The US clearly needs to step up efforts while using its alliances more forcefully in terms of technological cooperation. As for Europe, to avoid further marginalization, Europe and other global actors must learn from both the successes and failures of China's model, focusing on strategic coordination, market integration, and multilateral collaboration to foster resilient and competitive innovation ecosystems.

Introduction

The global technological landscape is being fundamentally altered by the intense competition in critical technologies, namely artificial intelligence (AI), semiconductors, and quantum computing. These domains now form the backbone of economic and strategic power, underpinning everything from autonomous systems and climate modeling to national security and economic resilience (García Herrero et al., 2025a). Control over these technologies increasingly determines global supply chain dominance and a nation's standing in the international order.

China's meteoric rise in these fields has been so rapid that many observers believe it is on the cusp of achieving the technological self-reliance Beijing has long pursued. The release of advanced, cost-efficient AI models like DeepSeek in early 2025, which outperformed some US benchmarks while navigating chip export restrictions, exemplifies this transformation and highlights China's growing ability to innovate around external constraints (García Herrero and Krystyanczuk, 2025). This progress, however, is not without its limitations. Despite massive state investment, China's innovation model faces significant headwinds, including persistent dependence on foreign technology, the inefficiencies of state-led allocation, and the impact of geopolitical tensions (García-Herrero and Weil, 2022).

This remarkable progress stands in stark contrast to the position of the European Union. While the US and China engage in a high-stakes technological rivalry, Europe finds itself increasingly relegated to a secondary role, struggling to generate breakthroughs and commercialize research at a competitive pace (García Herrero et al., 2025a).

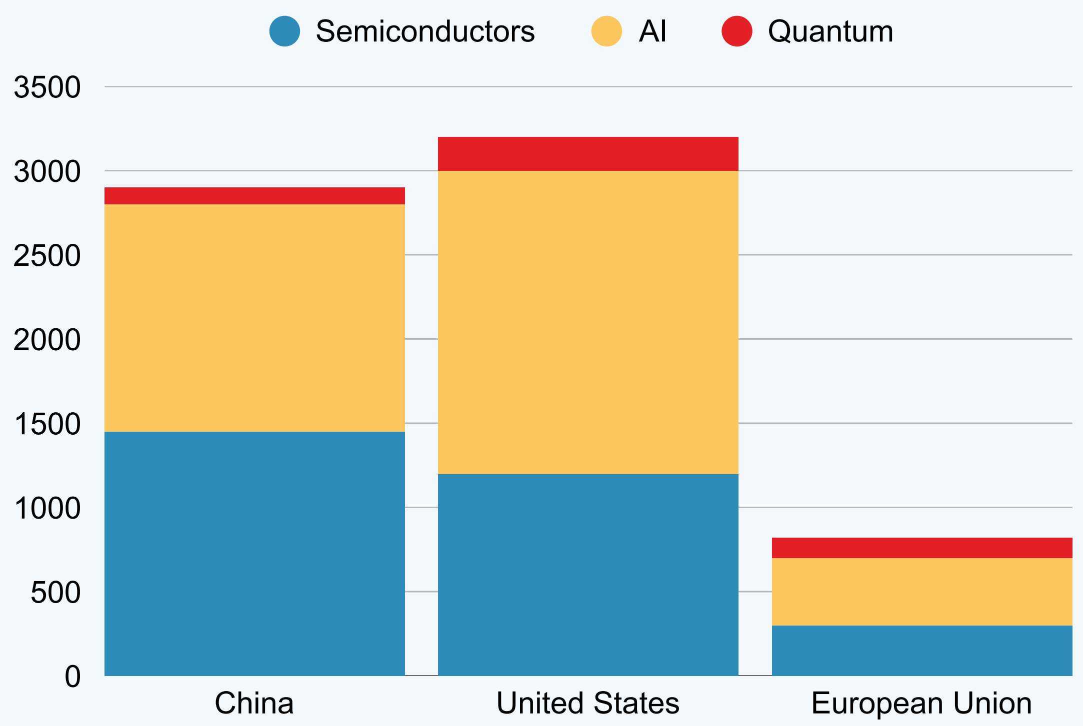
In this report, we analyze China's position in AI, semiconductors, and quantum computing relative to the US and EU. We examine its basic research capabilities, assess the speed at which its innovators replicate breakthroughs, and identify the key actors driving its technological surge. By providing a balanced assessment that acknowledges both China's strengths and its vulnerabilities, we aim to offer a nuanced understanding of the new global technological order and derive strategic policy recommendations for Europe and other nations seeking to maintain relevance in these critical domains.

China's Technological Position: A Race Toward Parity with Caveats

Since 2019, Chinese patent filings in AI, semiconductors, and quantum computing have experienced explosive growth, positioning China as a formidable global innovator. An analysis of 'radical novelties'—defined as breakthrough patents with no prior similar innovations that are subsequently replicated at least five times—reveals that China has made remarkable progress across all three domains. It now ranks second only to the US in AI and semiconductor radical novelties, with the gap narrowing rapidly. In quantum technologies, China's innovation output matches that of the EU, though both remain significantly behind the US (García Herrero et al., 2025a). This represents a dramatic shift in the global innovation hierarchy, with China emerging as the primary challenger to US technological supremacy.

However, a closer examination reveals a more complex and nuanced picture, where headline figures of progress mask significant underlying weaknesses and dependencies. China's achievements are uneven, with notable strengths in specific subfields but persistent lags in foundational areas, particularly those targeted by international export controls.

Figure 1: Radical Novelties by Headquarters (2019-2023)



Source: García-Herrero et al. (2025a).

Semiconductors: Strategic Gains and Enduring Bottlenecks

China's progress is most striking in semiconductor-related innovations, where it has dedicated enormous resources through initiatives like Made in China 2025 (García Herrero and Krystyanczuk, 2025). Chinese leadership is anchored in hardware-intensive and production-oriented subfields, where it accounts for 65% of novel patents filed by China, the EU, and the US combined. The focus on 3D stacking for high-density memory is particularly strategic, as this technology is critical for cutting-edge AI devices. This suggests China could potentially achieve full AI chip production capability if not for one critical constraint: lithography (García Herrero et al., 2025a).

Despite these gains, China's quest for semiconductor self-reliance has yielded underwhelming results in the most critical segments. After investing over $150 billion since 2015, China's success has been largely confined to the lower value-added parts of the supply chain, such as assembly and packaging (García-Herrero and Weil, 2022). In the fabrication of leading-edge logic chips, China's flagship company, SMIC, remains approximately five years behind global leaders like TSMC (ITIF, 2024). The country is even further behind in producing the sophisticated semiconductor manufacturing equipment (SME) needed for advanced nodes, especially extreme ultraviolet (EUV) lithography tools, which are a genuine bottleneck (VerWey, 2024; Network Law Review, 2025). Furthermore, China's massive state-led investment program, the "Big Fund," has been plagued by corruption and mismanagement, leading to high-profile bankruptcies and investigations that expose fundamental governance problems within the industry (The Heritage Foundation, 2022).

Artificial Intelligence: Applied Dominance and Software Gaps

In AI, China has established clear leadership in applied areas like computer vision for surveillance and autonomous systems, accounting for over 40% of radical novelties in these fields among the three major economies. In drone and aerial vehicle AI, Chinese firms lead with 55% of breakthrough innovations, pioneering swarm intelligence for logistics applications that surpass US and EU capabilities (García Herrero et al., 2025a). This progress is driven by both private market competition and significant state support, which has helped enhance the competitiveness of China's AI industry (RAND, 2025). While US-based institutions still produce more notable AI models overall—40 compared to China's 15 in 2024—the performance gap on major benchmarks has shrunk to near parity (Stanford HAI, 2025).

However, this rapid progress is constrained by the same hardware limitations affecting the semiconductor industry. US-led export controls on advanced AI chips are a major bottleneck, forcing Chinese companies to make trade-offs between near-term model development and building long-term resilience (RAND, 2025). Moreover, China faces a deficit in the software ecosystem. While Beijing is promoting domestic alternatives like Huawei's MindSpore and Baidu's PaddlePaddle, these frameworks lag significantly behind US counterparts like PyTorch and TensorFlow in terms of global adoption and community support (RAND, 2025).

Quantum Technology: Uneven and Opaque Progress

In quantum technology, where China lags most significantly behind the US overall, its progress is highly uneven. The nation has achieved global leadership in quantum communications, demonstrated by the development of the world's longest quantum key distribution (QKD) network and the Micius satellite (ITIF, 2024; USCC, 2025). It has also achieved excellence in specific sensing subfields, such as trapped-ion systems for precision measurement (García Herrero et al., 2025a). However, in the crucial area of quantum computing, China lags significantly, particularly in hardware development and practical implementation (ITIF, 2024). Most of its reported breakthroughs lack independent verification, blurring the line between genuine scientific progress and political signaling. This opacity, combined with a state-led consolidation that has seen private firms like Alibaba and Baidu shutter their quantum labs, may constrain the market-driven innovation necessary for long-term leadership (USCC, 2025).

China's Innovation Ecosystem: A Double-Edged Sword of State-Led Diversity

China's innovation ecosystem represents a fundamental departure from the US model, which is heavily concentrated in a few big-tech companies like Microsoft, IBM, and Google (García Herrero et al., 2025b). In contrast, China's landscape is characterized by its exceptional diversity, spanning multiple industries and institution types. This model blends strategic industrial policy with market-driven experimentation, creating a unique, albeit complex, competitive advantage (García Herrero and Krystyanczuk, 2025).

Huawei exemplifies this cross-domain approach, generating breakthroughs across AI, semiconductors, and quantum computing. Yet, China's true differentiator lies in the remarkable variety of contributors. In semiconductors, innovation comes from specialized firms like SMIC and Yangtze Memory, as well as telecommunications giants. In AI, breakthroughs emerge from unexpected sectors: insurance company Ping An leads in predictive health analytics, while consumer goods firm Haier contributes to data center cooling systems (García Herrero et al., 2025b). This diversity, spanning over 15 sectors with tight industry-academia connections, is actively cultivated by state policy. Programs like "Little Giants" incentivize any firm with high R&D intensity, creating a broad-based innovation ecosystem that links digital technologies with manufacturing capabilities.

Artificial Intelligence	Semiconductors	Quantum Computing
UBTECH Robotics	Yangtze Memory	Tencent
Tencent	TCL Technology	TCL Technology
Ping An	SMIC	South China Normal University
Oppo	Ningbo Semiconductor	Shenzhen Polytechnic
Huawei	InnoScience	Shenzhen Jingtai Technology
CloudMinds Robotics	Huawei	QuantumCTek
ByteDance	Enkris Semiconductor	Origin Quantum
Baidu	Cangxin Memory	Huawei
BOE Technology Group	BOE Optoelectronics	Hengtong Qasky Quantum
Autel Robotics	AAC Acoustic	China Electronics Technology Group

Source: García-Herrero et al. (2025b).

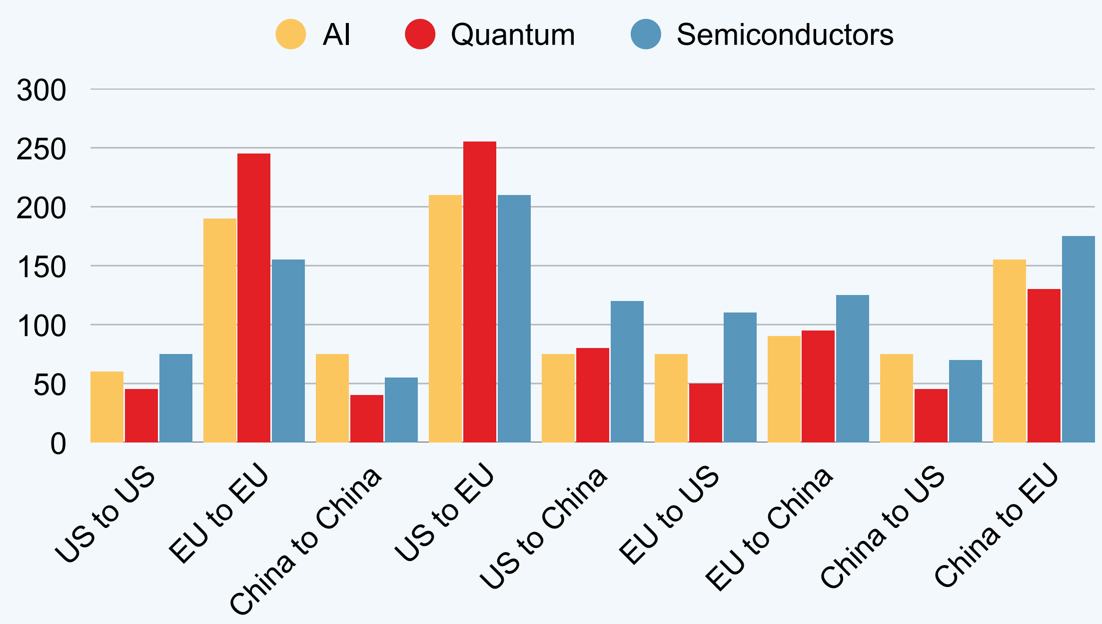
However, this state-guided model is a double-edged sword. While it effectively channels resources toward national priorities, it is not without significant drawbacks. The system is characterized by broader and more entrenched market distortions than in other economies (Rhodium Group, 2025). The close ties between government and industry can lead to cronyism, regional protectionism, and the misallocation of capital, as evidenced by the troubles in the semiconductor sector (García-Herrero and Schindowski, 2024). Despite the massive resources poured into industrial policy, China's productivity growth has been declining for two decades, suggesting that the state-led approach is not a panacea for innovation and may even create inefficiencies that hinder long-term, sustainable growth (García-Herrero and Schindowski, 2024).

Speed of Knowledge Absorption vs. Europe's Innovation Deficit

Perhaps China's most formidable competitive advantage is its extraordinary speed in replicating and adapting technological breakthroughs. In AI, Chinese innovators can replicate novel patents from the US or EU in just six months (García Herrero et al., 2025b). Most strikingly, this replication speed rivals that of US domestic innovation diffusion, meaning Chinese companies can adapt foreign breakthroughs nearly as quickly as American firms learn from each other. This capability, fueled by China's massive scale, industrial integration, and state coordination, effectively shortens the window of technological advantage for originating countries and neutralizes many of the benefits of being a first-mover.

While China rapidly closes the technological gap, Europe faces an increasingly dire innovation deficit. European innovators require 18-24 months to replicate novelties from either China or the US—a timeframe that is simply too slow for competitive relevance in fast-moving technological domains (García Herrero et al., 2025b). Even more concerning is Europe's sluggish internal innovation diffusion. The time required for a breakthrough from one EU country to be replicated in another often exceeds the time needed to replicate Chinese innovations. This internal fragmentation compounds Europe's external disadvantages.

Figure 2: Cross-Regional Spillovers by Direction *(average number of days)*



Source: García-Herrero et al. (2025b).

The fundamental challenge facing Europe is structural. Its innovation ecosystem relies heavily on public research centers, which, while producing high-quality research, limits commercialization speed and scale (García Herrero et al., 2025b). This is compounded by fragmented markets, a dependence on public funding that cannot match the depth of US venture capital or China's state-coordinated investment, and regulatory complexity. Ironically, the EU spends more on basic research than China in absolute terms, but China's expenditure growth rate is double that of the EU, meaning convergence is happening rapidly while Europe's relative position deteriorates (OECD, 2025). Without fundamental reforms, Europe will continue ceding ground in the technologies that define future economic and strategic power.

Policy Recommendations for the International Community

China's contested technological rise offers crucial lessons for the US, Europe, and other advanced economies. A successful response requires a multi-pronged strategy that goes beyond simply trying to contain China or copy its industrial policy. Instead, it must focus on strengthening domestic innovation ecosystems, fostering multilateral collaboration, and developing more sophisticated tools of economic statecraft.

For Europe: Overcoming Fragmentation and Building Scale

Europe's primary challenge is its internal fragmentation. To remain competitive, the EU must move decisively to create a truly integrated innovation market. First, it should redesign its institutions to accelerate the replication of breakthroughs. This could involve establishing a Critical Tech Observatory to monitor innovation in real-time and creating regulatory sandboxes to speed up patenting and commercialization (chinahorizons.eu, 2025). Second, the EU must refocus its funding instruments, such as Horizon Europe, to better bridge the gap between basic research and market application, potentially by integrating military and dual-use technology demand to boost scale and speed. Third, Europe must address its strategic dependencies. The Critical Raw Materials Act is a step in the right direction, but its targets for domestic extraction (10%) and processing (40%) by 2030 may be unrealistic without massive investment and partnerships with resource-rich third countries (European Commission, n.d.; Tech Policy Press, 2025). Finally, Europe must get real about China, recognizing that its trade and technological dominance poses a systemic challenge that requires a more assertive and unified defense of its economic security (Centre for European Reform, 2025).

For the United States: Refining Economic Statecraft and Fostering Alliances

The US has led the charge in using economic tools like export controls to slow China's technological advance. While these measures have created significant bottlenecks for Beijing, they are not a silver bullet and risk harming US innovation capabilities if not carefully calibrated (ITIF, 2025). The US should modernize its export control regime to be more effective and less fragmented. This includes consolidating authorities, which are currently dispersed across multiple agencies, into a single, integrated entity with enhanced intelligence capabilities and enforcement powers to counter evasion at an industrial scale (USCC, 2025). Furthermore, the US must shift from a unilateral approach to a multilateral one. Go-it-alone measures on technology transfer and talent flows are ineffective, as China can simply target other countries (Brookings, 2020). The US should work with allies in Europe and Asia to create plurilateral frameworks for coordinating on export controls, investment screening, and research security. This could involve expanding existing platforms like the Wassenaar Arrangement or creating new, more flexible coalitions focused on critical technologies (CSIS, 2024).

A Global Agenda: Promoting Resilient Supply Chains and Fair Competition

For the broader international community, the goal should be to build a global innovation system that is both competitive and resilient. This requires a concerted effort to diversify critical supply chains away from over-reliance on any single country. Advanced economies should co-invest in strategic projects in third countries, particularly for the mining and processing of critical raw materials, through frameworks like the EU's Global Gateway. This not only enhances supply chain security but also offers developing nations an alternative to Chinese-led investment. Moreover, international trade rules need to be updated to address the systemic market distortions caused by China's state-capitalist model. Existing WTO frameworks are ill-equipped to handle the scale and opacity of China's subsidies and non-market practices (Rhodium Group, 2025). Advanced economies must work together to develop legal instruments and enforcement mechanisms that can effectively discipline unfair trade practices and ensure a level playing field for all.

Ultimately, China's rise demonstrates that technological leadership is not permanent and that well-coordinated national strategies can rapidly alter global dynamics. The challenge for the rest of the world is not to halt China's progress, but to catalyze their own, building open, resilient, and collaborative innovation ecosystems capable of thriving in an era of intense strategic competition.

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