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High Tech Markets, Industrial Organization and Growth

Professor Gianpierro Torrisi

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The Semiconductor War: Technology and Geopolitics

Submitted by:

Rosario Pavone

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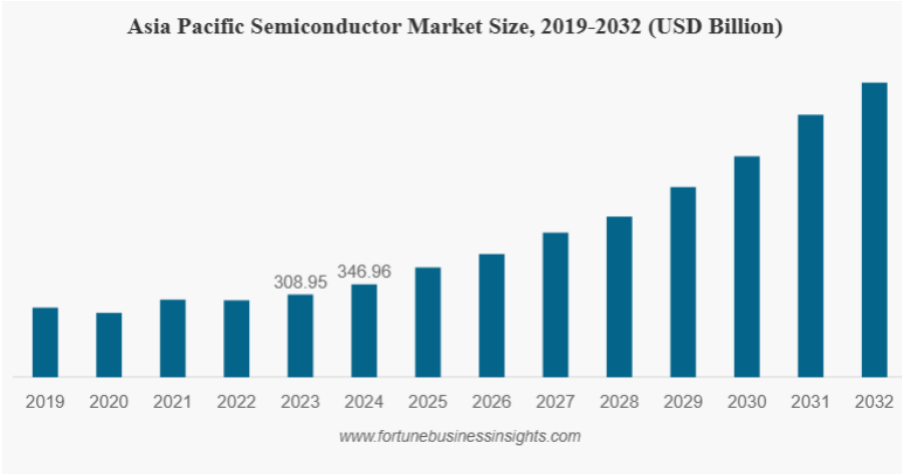
1 Introduction: The Semiconductor War and Global Competition

The semiconductor war is one of the most defining technological and economic conflicts of the 21st century, shaping global power dynamics and innovation. At the center of this struggle are the United States and China, whose race for semiconductor supremacy has led to escalating trade restrictions, geopolitical tensions, and a restructuring of global supply chains.The conflict gained momentum in the 2010s as China accelerated its technological advancements, raising concerns in Washington over intellectual property theft, cybersecurity, and economic security. In response, the Trump administration imposed sanctions on Huawei and SMIC, limiting China's access to advanced semiconductor technology. The Biden administration further tightened restrictions, expanding the Foreign Direct Product Rule and collaborating with Japan and the Netherlands to block China's access to essential chip-making equipment. While these measures have hindered China's progress in high-end semiconductor manufacturing, they have also driven Beijing to invest heavily in domestic innovation, as demonstrated by Huawei's recent breakthroughs despite Western sanctions. At the heart of this technological war is Taiwan, home to TSMC (Taiwan Semiconductor Manufacturing Company), which produces nearly 60% of the world's semiconductors. This dominance has made Taiwan a critical player in global geopolitics, with TSMC's CEO warning that a Chinese invasion would bring semiconductor production to a halt, potentially crippling multiple industries worldwide. The fragility of global supply chains became evident during the 2020 semiconductor shortage, which disrupted the automotive, consumer electronics, and telecommunications sectors. In response, governments worldwide have launched initiatives to strengthen their technological sovereignty and reduce dependence on Asian manufacturers: The European Chips Act (2022): A €11 billion investment aimed at boosting Europe's semiconductor industry. The US CHIPS Act (2022): A $52.7 billion initiative supporting semiconductor R&D, manufacturing, and workforce development. China's "Made in China 2025" Plan: A national strategy to achieve semiconductor self-sufficiency and reduce reliance on Western technology. Despite these efforts, the semiconductor industry faces ongoing challenges. China's zero-Covid policies, geopolitical uncertainties, and economic fluctuations continue to impact supply chains and production capacities. While declining demand for consumer electronics and automotive chips has led to falling semiconductor sales, the rapid growth of AI, cybersecurity, and cloud computing presents new opportunities for the industry. In the long run, the key question remains: will Western restrictions successfully hinder China's technological rise, or will they accelerate its push for self-sufficiency, ultimately reshaping the global semiconductor landscape? The competition between the US and China in the semiconductor sector is amplified by the presence of network effects and standardization strategies. As more companies develop AI and advanced technologies, the demand for next-generation semiconductors grows exponentially, strengthening the dominant players in the industry. Moreover, the battle over technological standards—such as new high-speed memory formats (HBM4)—plays a crucial role in shaping the future of industrial competition

2 Market Structure and Dominance of TSMC

The semiconductor industry, a cornerstone of modern technology, is primarily dominated by three major players: Taiwan Semiconductor Manufacturing Company (TSMC), Samsung, and Intel. These companies are at the forefront of chip manufacturing innovation, particularly in advanced nodes like 5nm, 3nm, and the upcoming 2nm processes. TSMC holds a dominant 64.9% market share in the global foundry market as of Q3 2024, reflecting its extensive customer base and unrivaled expertise in producing high-performance chips. The company leads in advanced process nodes, with 3nm chips representing 26% of its Q4 wafer sales, followed by 5nm (34%) and 7nm (14%). TSMC is pioneering the use of nanosheet transistor architecture, with its 2nm process set to enter mass production in the second half of 2025. This breakthrough promises to deliver significant improvements in both performance and energy efficiency, particularly benefiting fast-growing industries like artificial intelligence, 5G, and automotive technology. Although Samsung's market share dipped slightly from 11.5% in Q2 to 9.3% in Q3 2024, the company remains a formidable force in the industry. Samsung has made significant advancements in extreme ultraviolet (EUV) lithography, which is crucial for its 7nm and 5nm nodes. The company has also introduced gate-all-around (GAA) transistor technology in its 3nm process, which significantly enhances both power efficiency and performance. Samsung's promising 2nm (SF2) process is expected to enter mass production by Q4 2025, positioning the company as a direct challenger to TSMC. Intel has faced significant challenges in the foundry market, failing to rank among the top 10 foundries in Q4 2024. The company reported a $2.3 billion loss in its foundry division during this period, highlighting its struggles to meet market demands. Despite these setbacks, Intel remains committed to innovation, investing heavily in process node advancements and expanding its foundry services. The company is working on an ambitious roadmap to regain its competitive edge in the coming years. The sub-7nm race has become the battleground for next-generation devices, fueling intense competition within the semiconductor industry. TSMC thrives as a pure-play foundry, producing chips for clients like Apple, Nvidia, and AMD, without competing with them. Schumpeter's approach to economic growth emphasizes the crucial role of technological innovation as a driver of development. The semiconductor sector is a prime example of this theory: companies that heavily invest in R&D not only improve their competitive position but also contribute to overall economic growth. Governments support this process with strategic funding, as seen with the US CHIPS Act and China's backing of its domestic chip manufacturers. Samsung, despite facing challenges in market share, continues to invest heavily in R&D and maintains its integrated device manufacturer (IDM) model, serving both external clients and its own product lines. Intel, despite setbacks, is strategically repositioning itself to regain influence in the semiconductor space. Schumpeter's approach to economic growth emphasizes the crucial role of technological innovation as a driver of development. The semiconductor sector is a prime example of this theory: companies that heavily invest in R&D not only improve their competitive position but also contribute to overall economic growth. Governments support this process with strategic funding, as seen with the US CHIPS Act and China's backing of its domestic chip manufacturers. On a broader scale, the semiconductor market is experiencing rapid growth, driven by technological advancements and increasing demand across multiple industries. Valued at $611.35 billion in 2023, the market is projected to reach $2.06 trillion by 2032, growing at an impressive 14.9% compound annual growth rate (CAGR). Asia-Pacific leads the global market, accounting for 50.53% of the



share in 2023, while the United States is expected to reach $258.3 billion by 2032, driven by demand for consumer electronics and integrated circuit applications.

The industry is being transformed by innovations in artificial intelligence (AI), the Internet of Things (IoT), and machine learning, which are improving memory chip performance and accelerating data processing in data centers and industrial automation. Semiconductors have become essential across various sectors, including networking, consumer electronics, automotive technology, and government infrastructure projects. The automotive industry, in particular, is increasingly integrating semiconductor solutions into critical systems such as telematics, infotainment, safety features, and powertrains. Despite its promising growth trajectory, the semiconductor industry faces several challenges, including inventory management issues, high capital expenditures, and relentless pressure to innovate. However, major industry players such as Samsung, Apple, and Panasonic are making substantial investments in R&D, paving the way for groundbreaking new technologies. As demand for faster, high-performance memory chips increases—particularly in data centers and AI-driven computing—the semiconductor sector is poised to play a pivotal role in shaping the future of technology.

3 Technological dependence and competitive advantages arising from network effects.

Taiwan Semiconductor Manufacturing Company (TSMC) has firmly established itself as the global leader in semiconductor manufacturing, driven by cutting-edge technology, strategic investments, and strong industry partnerships. As demand for AI, 5G, and high-performance computing continues to surge, TSMC remains at the forefront of innovation, leading the development of advanced process nodes such as 5nm, 3nm, and the highly anticipated 2nm technology. These advancements have made TSMC the preferred partner for major technology companies, including Apple, AMD, and NVIDIA, which rely on its large-scale production capacity and consistently high-quality output. One of the less discussed aspects of the semiconductor war is the issue of switching costs. Dependence on foundries like TSMC is not just about production capacity but also about technological compatibility: shifting production to another supplier involves high costs and potential efficiency losses. This phenomenon is similar to what is observed in telecommunications, where the cost of interconnection between different networks can impact market competitiveness. Unlike competitors such as Samsung, which balances in-house chip production with contract manufacturing, TSMC operates as a pure-play foundry, focusing entirely on semiconductor manufacturing. This business model allows it to serve a broad range of clients without conflicts of interest, giving it a unique competitive advantage. Its substantial investment in research and development ensures continuous technological progress, reinforcing its leadership in the industry. Additionally, TSMC's ability to scale production efficiently helps maintain cost advantages, further solidifying its dominance in the global supply chain.

Company	2024 YoY Growth (%)	2025 YoY Growth (%)	2025 Market Share (%)	Trend
TSMC (TW)	25	25	66	→
SAMSUNG (KR)	3	9	9.2	↗
UMC (TW)	5	10	5	↗
Global Foundries (US)	-3	15	5	↗
SMIC (CN)	17	11	5	↘
HLMC (CN)	-4	13	2	↗
Tower (IR)	2	12	1	↗
PSMC (TW)	4	13	1	↗
VIS (TW)	13	12	0.9	→
Nexchip (CN)	20	14	0.9	↘
Others	-	-	4	-

At the same time, geopolitical factors have intensified the focus on semiconductor supply chain security. As tensions between the United States and China persist, countries in North America and Europe are actively working to reduce their dependence on Asia. This shift has only increased TSMC's strategic importance, with the company expanding its production facilities in Taiwan, the United States, and South Korea. However, challenges remain, particularly as nations seek to balance supply chain diversification with maintaining access to the most advanced semiconductor technologies. The rapid expansion of AI-driven applications is also fueling demand for specialized semiconductors such as Power Management ICs (PMICs), creating new opportunities for mature semiconductor manufacturing processes. While these developments present significant growth potential, ongoing geopolitical uncertainties, particularly efforts to decouple supply chains from China, may introduce hurdles for future production and expansion strategies. Despite these uncertainties, TSMC's technological expertise, strong partnerships, and market leadership position it to remain the dominant force in the semiconductor industry for years to come.

3.1 Global Semiconductor Market to Grow by 15 % in 2025, Driven

The global semiconductor market is expected to grow by 15% in 2025, driven primarily by increasing demand for artificial intelligence and high-performance computing. Advances in 2nm chip technology, high-bandwidth memory (HBM), and sophisticated semiconductor packaging techniques are expected to be key contributors to this growth. The memory segment is projected to expand by 24%, largely due to the widespread adoption of next-generation memory technologies such as HBM3, HBM3e, and the forthcoming HBM4, which are essential for AI accelerators. Meanwhile, the non-memory sector is expected to grow by 13%, driven by strong demand for AI servers, high-end mobile processors, and the emerging WiFi 7 standard. TSMC is anticipated to maintain its leadership in the foundry market, with its share projected to increase from 64% in 2024 to 66% in 2025. The company continues to lead in advanced node manufacturing, with significant investments in 2nm and 3nm production facilities across Taiwan, the United States, and South Korea. The mature semiconductor market, covering chips between 22nm and 500nm, is also experiencing a resurgence, fueled by increasing demand in consumer electronics and the automotive sector. Fab utilization rates are expected to surpass 75%, indicating a strong recovery for this segment.

In addition to chip fabrication, the industry is witnessing rapid growth in advanced packaging technologies, which enhance semiconductor performance and efficiency. TSMC is set to double its CoWoS (Chip-on-Wafer-on-Substrate) packaging capacity to support the growing AI chip demand from companies such as NVIDIA, AMD, AWS, and Broadcom. Fan-Out Panel-Level Packaging (FOPLP) is also gaining traction, particularly for radio frequency (RF) and analog chips, with potential future applications in AI processors. Geopolitical developments continue to reshape the semiconductor landscape. The ongoing U.S.-China trade tensions have accelerated China's efforts to expand its domestic semiconductor industry, while Taiwan and Southeast Asia are strengthening their roles as advanced packaging hubs. These shifts highlight the evolving nature of global supply chains and the increasing competition among nations to secure semiconductor production capabilities. Overall, the semiconductor industry is on track for significant expansion in 2025, but companies must navigate geopolitical challenges, supply chain adjustments, and market fluctuations. The continued rise of AI-driven applications and next-generation chip manufacturing will be key drivers of industry growth, shaping the future of the global semiconductor market.

4 TSMC extends dominance of semiconductors with 56 % share of global lithography systems

A recent report highlights China's growing dominance in semiconductor research, surpassing the United States in both the volume and impact of scientific publications between 2018 and 2023. During this period, Chinese researchers produced an impressive 160,852 papers on semiconductor-related topics, more than the combined output of the next three leading nations. The United States ranked second with 71,688 publications, followed by India and Japan. China's institutional contributions are equally significant, with nine of the world's top ten research institutions for semiconductor studies located within the country. Leading this effort is the Chinese Academy of Sciences, which not only has the highest number of published papers but also boasts a remarkable number of highly cited works. In total, China accounts for 23,520 highly cited publications, a key metric that underscores the influence and quality of its research. This surge in research activity reflects China's strategic push for technological self-sufficiency, particularly in response to U.S. sanctions and export restrictions on advanced semiconductor manufacturing equipment. With limited access to high-end lithography tools and other critical technologies, China has shifted its focus toward innovations in chip design and fabrication. The country's academic institutions have also benefited from an influx of returning scientists, further strengthening its knowledge base and research capabilities. However, despite these advancements, significant challenges remain. While China leads in research output, it has yet to close the gap in the production of high-end semiconductors, where U.S. export controls continue to restrict access to essential manufacturing tools. Additionally, concerns persist regarding the quality of some research outputs, as reports of fraudulent or low-quality "paper mill" publications have raised questions about the credibility of certain studies. Ultimately, while China's research dominance is reshaping the global semiconductor landscape, the country still faces barriers in translating academic progress into cutting-edge semiconductor manufacturing capabilities. Whether it can overcome these challenges will play a crucial role in determining its future position in the industry.

5 How Taiwan's TSMC dominated the chip market

TSMC has solidified its position as the dominant force in the global semiconductor foundry market, further widening its lead over Samsung Electronics, which faces mounting challenges from both Taiwan's semiconductor giant and emerging Chinese competitors. By 2024, the market share gap between TSMC and Samsung had expanded to over 50 percentage points, highlighting Samsung's struggle to keep pace, especially as China's Semiconductor Manufacturing International Corporation (SMIC) gains ground with strong government backing. According to Lin Hong-wen, a leading expert on TSMC and author of Chip Island: How TSMC and Taiwan Triumph, Samsung must accelerate its transition to advanced node processes to remain competitive. The company's continued reliance on legacy nodes has left it vulnerable to increasing competition, and Lin argues that Samsung should adopt a strategy centered on differentiation and irreplaceability. This philosophy aligns with the "super gap" approach once championed by the late Samsung Chairman Lee Kun-hee, who believed in maintaining a technological edge that rivals could not easily replicate. TSMC's success stems from its specialized foundry model, a strategy it has pursued since its founding in 1987. Unlike companies in

Korea, Japan, and China that follow vertically integrated models, TSMC capitalized on the industry's shift toward vertical specialization. By dedicating itself solely to contract manufacturing and prioritizing customer needs, it secured its place as the world's leading foundry. Although it initially faced stiff competition from Taiwanese rival UMC and later from Samsung, TSMC repeatedly outmaneuvered its competitors. A pivotal moment in TSMC's rise was its creation of the "Night Hawk Squad", an initiative that successfully won back Apple's business from Samsung, demonstrating its ability to adapt and compete aggressively. Another crucial factor behind TSMC's dominance is its deep ties with the United States, as over 60% of its customers are American tech firms. Many of its senior executives hold PhDs from U.S. institutions and have prior experience in multinational corporations, strengthening the company's relationships with key clients. However, Lin emphasizes that TSMC's leadership is not solely a result of its U.S. connections but also its ability to evolve alongside the global semiconductor ecosystem. Looking ahead, TSMC's technological leadership in advanced process nodes and continued investments in next-generation technologies will likely sustain its market dominance. However, China's aggressive expansion in legacy semiconductor manufacturing presents a new challenge. Unlike Taiwan, which focuses on high-value-added services and differentiation, China prioritizes market share over profitability, flooding the industry with lower-cost alternatives. This strategy could further disrupt the market and intensify pressure on companies like Samsung. Samsung's current struggles stem from multiple factors. The company faces stiff competition from Chinese firms across several sectors, from smartphones to memory chips. The rapid rise of AI-driven demand has reshaped the semiconductor market, with TSMC leveraging its CoWoS packaging technology to integrate NVIDIA's GPUs and SK Hynix's high-bandwidth memory (HBM)—a lucrative opportunity that Samsung failed to capitalize on. Additionally, Japan's 2019 export restrictions on essential semiconductor chemicals disrupted Samsung's supply chain, causing manufacturing delays. Leadership challenges following Lee Kun-hee's passing in 2020, coupled with external disruptions such as the U.S.-China trade war and the COVID-19 pandemic, further complicated the company's trajectory. For Samsung to regain its competitive edge, it must streamline decision-making and restructure its internal organization. The vast scope of its operations, spanning multiple product lines and business divisions, has stretched leadership resources too thin, slowing strategic execution. Internal conflicts between business units hinder collaboration, and without structural changes, the company risks falling further behind. TSMC's success offers valuable lessons for Samsung. Its commitment to customer trust, mutual growth, and fostering a culture of innovation has been instrumental in securing long-term leadership. If Samsung hopes to reverse its decline, it must focus on rebuilding client relationships, fostering internal cohesion, and narrowing its strategic focus to areas where it can truly differentiate itself from competitors.

6 Industrial Policy in the Global Semiconductor Sector

The semiconductor industry is undergoing a profound transformation. Demand continues to rise, driven by advancements in artificial intelligence (AI), the automotive sector, and the Internet of Things (IoT). However, the industry faces significant challenges, including unstable supply chains, rising production costs, and increasing geopolitical tensions, all of which make market navigation more complex. To stay competitive, semiconductor companies are investing heavily in cutting-edge technologies, pushing fabrication nodes down to 2 nanometers (nm) and adopting chiplet architectures to enhance performance and energy efficiency. Despite these technological advancements, several uncertainties remain. Raw material availability, evolving regulatory frameworks, and market fluctuations continue to impact global supply chains. In certain segments, demand slowdowns could lead to an oversupply situation, exerting downward pressure on semiconductor prices. Nonetheless, the industry still presents significant growth opportunities. The rise of AI-driven applications, edge computing, and the emergence of 6G signal a promising future for semiconductor innovation. Companies that effectively diversify their strategies, strengthen global partnerships, and adapt to shifting market conditions will be best positioned to lead in the coming years.

7 Conclusion

The semiconductor industry plays a pivotal role in global technological progress and geopolitical power dynamics. Its future will be shaped by continuous innovation, strategic investment, and international cooperation, ensuring stability and sustained growth in an increasingly competitive landscape. The growing reliance on semiconductors in AI, telecommunications, defense, and consumer electronics underscores their critical role in modern economies. As nations strive to secure semiconductor supply chains and maintain technological supremacy, global competition over manufacturing capabilities and intellectual property rights has intensified, prompting significant policy shifts worldwide. The semiconductor industry is characterized by intense patent competition, leading to the creation of patent thickets—an excessive overlap of patents that can hinder innovation rather than encourage it. This situation can result in an 'anticommons effect,' where no company can fully exploit a technology without negotiating with multiple patent holders, slowing technological progress and increasing development costs To maintain a competitive advantage, both countries and corporations must continue investing in research and development (R&D), fostering technological breakthroughs that will drive the next generation of computing, automation, and energy-efficient chip designs. Moreover, diversifying manufacturing bases and supply chains will be crucial in mitigating risks associated with geopolitical conflicts, trade restrictions, and natural disasters, all of which have the potential to disrupt global semiconductor production. Collaboration between governments, industries, and academic institutions will be instrumental in overcoming technological bottlenecks and ensuring a resilient semiconductor ecosystem. Nations that successfully balance national security concerns with international cooperation will be better positioned to lead the industry in the coming years. Looking ahead, the ongoing "semiconductor war" highlights the intersections of technology, economics, and geopolitics, with profound implications for global power structures. Moving forward, strategic foresight, innovation-driven policies, and cooperative international frameworks will be essential for navigating the evolving semiconductor landscape, ensuring sustainable growth and technological progress for years to come.

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