Taiwan's Semiconductor Fabrication Industry Monopoly: Analyzing Attempts At Market Diversification

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As economies around the world grow in production and consumption capacity, reliance on semiconductors also increases. From kitchen appliances to hand-held electronics to motorized vehicles, semiconductors are more prevalent than most comprehend. Unlike other booming industries however, semiconductor and microchip markets present an interesting puzzle to economists and policymakers; the majority of semiconductor fabrication occurs in Taiwan, where volatile geopolitics threaten global supplies. A number of attempts have been made to address this issue, although it is crucial to contextualize this problem to understand how to stabilize the industry. This essay will evaluate Taiwan's historical success as a microchip fabricator, explaining how Taiwan Semiconductor Manufacturing Company Ltd. (TSMC) became a prominent figure in the industry. The paper will subsequently analyze Taiwan's "Silicon Shield" in the context of national security concerns, and evaluate market diversification attempts, particularly by the United States.

TSMC has a monopoly over the microchip industry that is crucial to analyze, given the push for more market diversification. AnnaLee Saxenian from the University of California, Berkeley reflects on Taiwan's growth post 1980. IT industrial output at the beginning of this period totaled less than $100 million USD, jumped more than $5 billion by 1989, and has grown 20% annually since the 1990s.[1] As countries like the United States fund domestic production to address security concerns regarding microchips in the Republic of China (ROC), amounts of capital, prospective timelines, and available resources are all important contextual factors to consider in understanding potential transferability of TSMC's growth process to other firms.

Taiwan's industrial growth following TSMC's successful investment returns on technology required for the development of microchips was strategic and planned. Even after the development of this technology, entry into the market remained difficult; microelectronics have always been relatively capital intensive, which on a competitive level is inaccessible to many new market entrants.[2] In the decades that followed the development of nano-technology, the government provided manufacturing subsidies and focused on strong market subsidies. This largely created a decentralized economic ecosystem that also fueled the downstream development of tech startups, furthering the monopoly on research & development in the global IT industry.[3] This was also supported by technology transfer between the United States and Taiwan. In this regard, a foundational element of TSMC's growth as supported by Taiwan's developmental state is the internationalization of TSMC business and technology. A strong relationship between TSMC and Silicon Valley supported the entrepreneurship that allowed Taiwan to consistently remain the founders of break-through technology. Feigenbaum

[1] AnnaLee Saxenian, "The Urban Contradictions of Silicon Valley: Regional Growth and the Restructuring of the Semiconductor Industry," *International Journal of Urban and Regional Research* 7, no. 2 (1983): 237–62, https://doi.org/10.1111/j.1468-2427.1983.tb00592.x.

[2] Jared Monschein, "Securing the Microelectronics Supply Chain: Four Policy Issues for the U.S. Department of Defense to Consider," *RAND Corporation*, 2022, https://doi.org/10.7249/pea1394-1.

[3] Feigenbaum, Evan A. "Historical Context of Taiwan's Technological Success." *Assuring Taiwan's Innovation Future*. Carnegie Endowment for International Peace, 2020. http://www.jstor.org/stable/resrep20992.6.

describes this relationship: "Taiwan, in effect, discovered Silicon Valley decades before the rest of the world. That discovery—and the process of "brain circulation" of Taiwan-born but U.S.-educated and -trained engineers and entrepreneurs—in turn drove a wave of entrepreneurial growth in semiconductors, PCs, and other hardware-related industries." [4] Through this relationship and in the symbiotic nature of technological exchange between the United States and Taiwan in the 1980s, Taiwanese manufacturing shifted from centralization of low-cost imitators to high-speed, high-quality, and extremely competitive electronics at competitive market prices. Certain elements such as cheaper labor contributed to Taiwan's growing advantage in semiconductor fabrication. American market founders such as Fairchild, National Semiconductors, and Intel established the semiconductor market, but soon lost their comparative advantage as Taiwan's labor advantage combined with quality, specialization, and production capabilities contributed to cheaper Taiwanese semiconductors on global markets.

The development of the foundry model around this time is also crucial in understanding the role TSMC played in the global semiconductor industry. TSMC was designed to only manufacture Integrated Circuits (ICs), and was the first company to do so. Rather than firms that design and manufacture their own ICs, TSMC contracts with other firms including Apple, Intel, and Broadcom to fabricate the designs of those companies with technology specific to TSMC, such as EUV lithography and analog processing. At the time TSMC started operating with this business model in the 80s, the semiconductor industry was almost entirely vertically integrated, but the foundry model allowed for firms to only focus on chip design or manufacturing, and thus developing advanced technology explicitly for that certain part of the semiconductor supply chain.[5] As previously mentioned, TSMC is the main manufacturer of many prominent companies, and the world is largely reliant on the company's fabrication capabilities. However, there are numerous security issues pertaining to geopolitics in light of this issue.

Recently, Taiwan's "Silicon Shield" has been increasingly analyzed and evaluated. As security concerns have brought to attention the CHIPS and Science Act of August 2022, international consumers of microchips are calling for greater market diversification and subsidies for domestic production. In understanding this relationship, it is important to recognize the semiconductor supply chain implications.

While TSMC actively participates in most parts of the supply chain, the company maintains a proportionally higher participation ratio in the market for fabrication. Other countries, including the United States, have attempted to counteract this in numerous ways, including an increase in subsidies for domestic production of semiconductors, so as to create a more self-sufficient supply of ICs. Growing concerns surrounding the risk of an annexation attempt, among other things, between the People's Republic of China (PRC) and ROC have increased these uncertainties. The United States is home to many firms that depend on Taiwanese microchip production, such as Apple, Intel, NVIDIA, and Broadcom, which contribute to domestic economic growth, foreign direct investment, and employment. Therefore, protecting these firms politically is in the United States' best interest. A ROC confrontation with the PRC, even in the event of a partial naval blockade, could hinder Taiwan's ability to ship microchips elsewhere in the supply chain, which could hold serious

[4] Feigenbaum, Evan A. "Historical Context of Taiwan's Technological Success." *Assuring Taiwan's Innovation Future*. Carnegie Endowment for International Peace, 2020. http://www.jstor.org/stable/resrep20992.6.

[5] J H Chen, "A System Dynamics Model of the Semiconductor Industry Development in Taiwan," *Journal of the Operational Research Society* 56, no. 10 (2005): 1141–50, https://doi.org/10.1057/palgrave.jors.2601958.

ramifications. Taiwan as of 2021 was the 16th largest trading economy, with imports and exports of $922 billion in goods and services. While largely impossible to predict the scale of consequences this blockade could have, estimates from the Rhodium Group consider primary exports and imports and suggest that around $2 trillion in economic activity could be affected, even before taking into account secondary effects and sanctions.[6] As such, the United States should protect Taiwan economically, thus giving Taiwan a "Silicon Shield."

A number of global attempts at diversification have been made, notably the CHIPS and Science Act, signed by the U.S. Congress in August 2022, which includes $280 billion for research, development, and manufacturing for semiconductors in direct funding and subsidies. Much of this funding is funneled into the industry as a whole, rather than funding firms directly. Growing concerns over this act include worries that timelines for growing the American semiconductor industry are unrealistic and that the semiconductor industry growth models pertaining to Taiwan are the product of many decades of technological developments and research. Additionally, there are a number of other countries including Japan, the Netherlands, and South Korea, that incentivize domestic production with more strategic planning, particularly related to microchips in mass consumption and weapons systems.[7]

To increase political and economic security, the PRC has attempted to decrease its reliance on the ROC for semiconductors. While much of this is accomplished through increased incentives for domestic production, other sources of semiconductor independence have involved technological espionage. The ROC maintains a ban that prevents PRC chip design companies from partnering with ROC manufacturers for fabrication. This ban is parallel to the United States banning the PRC from chips made anywhere in the world with U.S. equipment, preventing the PRC from sourcing chips from anywhere in the supply chain with US technology or resources.[8] These initiatives reflect efforts to prevent PRC independence from the international semiconductor market, which would both render the"Silicon Shield" obsolete and exacerbate ROC security concerns.

The "brain drain" to the PRC from the ROC has threatened Taiwanese technological talent and technology for decades. The PRC has consistently offered better wages, scholarships, and benefits, which has attracted many engineers trained in the ROC with knowledge of semiconductor capabilities to move to the mainland and work for those firms. Salaries in the PRC can reach three times those in the ROC.[9] The ROC has made this increasingly difficult for the PRC; while it is not illegal to hire Taiwanese engineers, re-employment in the ROC after working in the PRC is considered traitorous.[10] Additionally, PRC investment in certain parts of the supply chain, such as design and packaging, are illegal and make it difficult for PRC firms to commit technological espionage or ship technology back to the mainland.[11] To circumvent this business

[6] Charlie Vest, "The Global Economic Disruptions from a Taiwan Conflict," Rhodium Group, May 12, 2023, https://rhg.com/research/taiwan-economic-disruptions.
[7] Jared Monschein, "Securing the Microelectronics Supply Chain: Four Policy Issues for the U.S. Department of Defense to Consider," *RAND Corporation*, 2022, https://doi.org/10.7249/pea1394-1.

[8] Gregory C. Allen, "Choking off China's Access to the Future of Ai," CSIS, 2022, https://www.csis.org/analysis/choking-chinas-access-future-ai.
[9] Sarah Wu Yimou Lee, "'Tip of the Iceberg': Taiwan's Spy Catchers Hunt Chinese Poachers of Chip Talent," Reuters, April 8, 2022, https://www.reuters.com/world/asia-pacific/tip-iceberg-taiwans-spy-catchers-hunt-chinese-poachers-chip-talent-2022-04-08/.
[10] Erin Hale, "Taiwan Cracks down on China Poaching Tech Talent," Technology | Al Jazeera, May 4, 2022, https://www.aljazeera.com/economy/2022/5/4/taiwan-is-trying-to-thwart-chinas-efforts-to-poach-tech-talent.
[11] Jared Monschein, "Securing the Microelectronics Supply Chain: Four Policy Issues for the U.S. Department

obstacle, the PRC has been known to create puppet companies, or offshore firms that hinder ROC and American personnel efforts to detect intelligence stealing. Much of this has been done in low-income countries, off of the ROC's radar of suspicion for technological espionage, particularly in attempts to hire Taiwanese engineers, or "poach Taiwanese talent".[12] The challenge for the ROC in this context is to limit this "poaching" without completely limiting foreign direct investment, which is prevented with stricter controls on international investments in firms and international shareholdings. This, however, is supported by multilateral semiconductor export controls between other prominent countries that participate in the supply chain.

Some of the most effective attempts at preventing the PRC from accessing Taiwanese technology and semiconductors have been joint agreements between countries with semiconductor fabrication capacity to discourage gap replacements in the market after the United States implements export controls on semiconductors. As previously mentioned, the United States bans Taiwan from semiconductors and American technology that has been made with American resources, labor, or materials. Given that this gap in the market leaves room for other producers to fill in with their own capital, joint agreements have been signed to more effectively collectivize against the PRC having free access to global semiconductor markets and technology. An example of this is the multilateral semiconductor export control that was established between the United States, Japan, and the Netherlands; the details of the agreement specify that Japan and the Netherlands will not allow their technology to replace U.S. industry sales to the PRC.[13] This agreement as a whole has the power to prevent the PRC from gaining semiconductor production self-sufficiency, which has the potential to undermine the ROC's "Silicon Shield." This agreement in particular reflects changing interests; previous stances include Japanese and Dutch fear of PRC retaliation given the event of a multilateral export control against the PRC, but recent threats of retaliation have been damaged by the PRC's stance and involvement with the Russian-Ukraine war.[14] In this way, it is apparent that the international community is attempting to diversify the semiconductor fabrication industry while maintaining national security interests and fair practices. However, initiated attempts at this push for domestic production should be evaluated in the context of their potential to be effective relative to their strategies.

The most recent CHIPS and Science Act has three goals: reducing the U.S. supply chain's exposure to foreign shocks, bolstering long-term international economic competitiveness and creating domestic jobs, and reducing the risk of sabotage.[15] While these objectives should be prioritized, the methodology for the goals has been questioned. Primarily, the discussion surrounding the issue of semiconductor supply chain diversification has centered around fabrication, without much attention towards design, packaging, testing, etc. The CHIPS and Science Act has allowed for

of Defense to Consider," *RAND Corporation*, 2022, https://doi.org/10.7249/pea1394-1.

[12] Erin Hale, "Taiwan Cracks down on China Poaching Tech Talent," Technology | Al Jazeera, May 4, 2022, https://www.aljazeera.com/economy/2022/5/4/taiwan-is-trying-to-thwart-chinas-efforts-to-poach-tech-talent.

[13] David Shepardson, "U.S. Official Acknowledges Japan, Netherlands Deal to Curb Chipmaking Exports to China," Reuters, February 1, 2023, https://www.reuters.com/technology/us-official-acknowledges-japan-netherlands-deal-curb-chipmaking-exports-china-2023-02-01/.

[14] Gregory C. Allen, "In Tech War with China, the U.S. Is Finding Friends," Time, February 23, 2023, https://time.com/6257857/us-china-tech-war-semiconductor/.

[15] Vishnu Kannan and Jacob Feldgoise, "After the Chips Act: The Limits of Reshoring and next Steps for U.S," Carnegie Endowment for International Peace, November 2022,https://carnegieendowment.org/2022/11/22/after-chips-act-limits-of-reshoring-and-next-steps-for-u.s.-semiconductor-policy-pub-88439.

investment and funding for these different parts of the semiconductor supply chain, but does not have any requirements in place to do so. There are many parts of this supply chain that are vulnerable not only to political instability in East Asia, but also geographic factors, such as many ATP facilities existing on the Pacific's Ring of Fire.[16] Additionally, much of the emphasis on TSMC's fabrication capabilities has drawn US policy maker attention from the ways that the industry relies on second and third tier supplies of other sources of capital:

> "These companies produce industrial machinery, specialty chemicals, crystal growth equipment, and a wide range of other essential products. Japanese firms, for example, are dominant producers of semiconductor materials (24 percent market share) and semiconductor manufacturing equipment (31 percent market share); global dependence on Japanese materials firms is particularly pronounced in wafer production (56 percent market share) and photoresist (90 percent market share). Supply shocks in those industries, whether the result of natural disasters or malicious interference, can also lead to chip shortages. Yet, in the rush to construct new fabs, policymakers have paid relatively less attention to these suppliers."[17]

In this passage, it is apparent that focusing on fabrication of microchips neglects the other elements of the semiconductor supply chain that need to be secured and supported. Funding for the semiconductor industry must address sources of materials and work to grow different elements of the supply chain so as to not create an industrial-wide bottleneck. In addition to funding concerns in the supply chain, support from the CHIPS and Science Act for only fabrication exacerbates security concerns. CHIPS and Science Act-funded facilities would be less likely to be vulnerable to technological espionage, but smaller scale covert attacks as well as espionage in other parts of the supply chain still remain a threat. Protection of the ATP phase is important in this regard: Attacks targeting the fabrication phase, some experts argue, "are high cost and require generating at least one new mask set, an in-depth analysis of the device, and a high degree of expertise. Additionally, they are imprecise, as attackers can rarely be sure that the altered hardware will make its way into specific end-use products. This potentially makes the ATP phase an easier and more attractive target."[18] In this way, if one of the goals of the CHIPS and Science Act is to reduce the risk of sabotage, it is important to consider the most realistic ways this can be prevented.

To counteract issues with semiconductor supply chain bottlenecks, the CHIPS and Science Act needs to work with firms on support for different parts of the supply chain. General funding for industrial growth neglects parts of the supply chain that are necessary for development.[19] The government in this way must coordinate industry growth in tangent with firms to secure the development of all necessary parts of the

[16] Vishnu Kannan and Jacob Feldgoise, "After the Chips Act: The Limits of Reshoring and next Steps for U.S," Carnegie Endowment for International Peace, November 2022, https://carnegieendowment.org/2022/11/22/after-chips-act-limits-of-reshoring-and-next-steps-for-u.s.-semiconductor-policy-pub-88439.

[17] Vishnu Kannan and Jacob Feldgoise, "After the Chips Act: The Limits of Reshoring and next Steps for U.S," Carnegie Endowment for International Peace, November 2022, https://carnegieendowment.org/2022/11/22/after-chips-act-limits-of-reshoring-and-next-steps-for-u.s.-semiconductor-policy-pub-88439.

[18] Vishnu Kannan and Jacob Feldgoise, "After the Chips Act: The Limits of Reshoring and next Steps for U.S," Carnegie Endowment for International Peace, November 2022, https://carnegieendowment.org/2022/11/22/after-chips-act-limits-of-reshoring-and-next-steps-for-u.s.-semiconductor-policy-pub-88439.

[19] Chun-Yi Lee, "Semiconductors and Geo-Technology: 'Know-How' Is Power." Freeman Spogli Institute Winter Seminar Series. 8 Mar. 2023, Stanford.

semiconductor supply chain, rather than non-specific industry funding. General subsidies for semiconductor fabrication in the United States might have the potential to allow the United States to manufacture its own microchips, but in reality it is threatened by lack of support for other areas in the semiconductor industry.

Semiconductors are becoming an increasingly crucial part of our globalized world. From cars to refrigerators to virtually all phones, semiconductors influence our technological reality in many ways. As this dynamic becomes increasingly intertwined with Taiwan's monopoly on the semiconductor production industry, as well as both ROC-PRC and U.S.-PRC security concerns, it is important to consider different interests and how they are affected by attempts at market diversification. The CHIPS and Science Act pushes for U.S. domestic production of semiconductors but lacks the collaboration between firms and government needed to support other parts of the semiconductor supply chain. While there is no obvious best policy to create more economic security in relation to microchip supply, it is crucial that we address challenges and obstacles to continued industrial growth.