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High-tech Development in Late Developing States: Taiwan's Semiconductor Success

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Chapter 1:

Taiwan's Semiconductor Success: State and Network-led Development

Taiwan is an island nation with a population less than Shanghai, but the island's largest semiconductor firms, Taiwan Semiconductor Manufacturing Corporation (TSMC) and United Microelectronics (UMC), maintain more than half of the world's semiconductor foundry market share.[1] Taiwan's emerging economy is perhaps more distinguished than prominent late-comer neighbors such as Korea, Hong Kong and Singapore, because it is the only economy to not only catch-up within a high tech industry such as semiconductors, but also produce at the cutting edge of industry innovation. Taiwan's semiconductor industry success is well matched with the life and career of recently retired TSMC Chairman and CEO Morris Chang. Mr. Chang was one of Taiwan's first generation of engineers studying in the United States, where he earned degrees in Mechanical Engineering from M.I.T, as well as a PhD in electrical engineering from Stanford University. He spent the majority of his early career working for Texas Instruments as a senior

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[1] Clair Brown and Greg Linden, "Crisis 2: Rising Cost of Fabrication." in *Chips and Change : How Crisis Reshapes the Semiconductor Industry*, (Cambridge: MIT Press, 2009), 39.

Vice President overseeing semiconductor production. After years of attaining and absorbing knowledge, business practices and know-how, in 1985 Chang shifted his attention homeward by serving as the Chairman for Taiwan's Industrial Technology Research Institute. TSMC was officially created in 1987 as a joint venture between the Taiwan government (ITRI), the Dutch multinational corporation (MNC) Phillips, as well as private investors, with Chang leaving ITRI to lead the new venture. Chang claims the establishment of TSMC "ushered in a new era in the electronics industry-that of the dedicated silicon foundry." [2]

While Chang's inception of the foundry-fabless organization of the semiconductor supply chain indeed manifested into a reality, one should also consider political and economic structural factors supporting the establishment of TSMC and the foundry-fabless style of production. Certainly, the fragmentation of global production and business trends like outsourcing and the vertical disintegration of industries helped Taiwan's foundry sector success. Additionally, scholars like Anna Lee Saxenian suggest the connections and know-how Chang and other returnee entrepreneurs attained abroad (Network-led), is more important for Taiwan's semiconductor success than the industrial and State policy of Taiwan (State-led). Which factor is more important for Taiwan achieving and maintaining the technological cutting edge in semiconductor fabrication, and did this dramatic change in organized production influence the State's ability to impact development decisions? In other words, how is Taiwan's ability to direct development impacted by the vertical disintegration of the global semiconductor industry, and where is the center of development decision making power located?

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[2] M Chang, "Foundry Future: Challenges in the 21st Century," *2007 IEEE International Solid-State Circuits Conference. Digest of Technical Papers,* San Francisco, CA, pp. 18-23.

Literature Review

To most scholars, explanations for high-tech development in late emerging economies are either founded in an emphasis on State-led policy initiatives and infrastructure providing private enterprises the necessary inputs for innovation, or a focus on transnational networks of industry links, as well as the influx of a market economy attempting to find the correct market prices. Within the context of Taiwan, political economist Dan Breznitz argues the 'Innovation State' primarily deserves credit for the successful semiconductor foundry sector in Taiwan due to initial research development initiatives of public research consortia, such as ITRI and Electronic Research Service Organization (ERSO), creating spin-off companies like United Microelectronics (UMC) and TSMC, as well as initially attaining foreign technology for IC fabrication from firms like RCA. While Breznitz largely credits the Taiwanese government for the initial development of the nation's semiconductor industry, significantly he adds that continued development is in part due to the State's willingness and ability to give up development decisions once a relatively strong private sector semiconductor foundry industry emerged.[3] In other words, he claims the Taiwanese State focused on aiding and upgrading domestic firm development and capabilities, specifically the physical manufacturing of semiconductor chips, in order for these firms to attain the technological level and leverage needed for firm to firm interactions when entering the global semiconductor industry. Breznitz credits State policy for actively targeting these MNC's and points to policies such as the

[3] Dan Breznitz, "The Development of the IT Industry in Taiwan: Public Research Institutions as Growth Impetus?" in *Innovation and the State: Political Choice and Strategies for Growth in Israel, Taiwan, and Ireland* (New Haven; London: Yale University Press, 2007), 99.

establishment of the world's first export-processing-zone and favorable tax incentives initially attracting top foreign firms, such as Dutch MNC Phillips, to Taiwan. These policies undoubtedly incentivized firms to move production to Taiwan, but without strong domestic firm capabilities there is no incentive for firms to move focus away from relative low labor costs assembly and testing stages of production. The most important factors in Taiwan's high-tech semiconductor development is not favorable tax policies or low environmental standards, but instead are domestic firms ability to transition from low-end tech activity to achieving the global technological cutting edge.

State Driven Theories of Development

In the following section, we will analyze the arguments of prominent Statist literatures as well as State-driven development arguments tailored specifically for Taiwan's high-tech industries. In an attempt to provide nuanced understandings and complex analysis of Breznitz' and other claims, we will address their claims with no abstention of prominent criticisms. We will compare Breznitz' arguments with alternative theories for high-tech development, like Saxenian's network led theory, and find if they are in contradiction and or agreement with each other.

Breznitz's theoretical framework largely stems from and is supported by literature of the developmental state. Stephen Haggard in his book *Developmental States* looks at the relationship between intervention and growth in developing economies. Statist literature, including Haggard's, claims state action can overcome weak areas of either market failure, technology

transfer, adoption and learning. The positive relationship Haggard claims to exist offers theoretical evidence to explain the practical success of Taiwan's semiconductor industry and supports Breznitz' argument "the state (Taiwan) itself, acting as the technology-creating agent, has spurred the growth of the IT sector… by embedding public research institutions within the technology-creating sector."[4] ITRI is the most successful of these public research institutes and served a variety of functions for developing Taiwan's semiconductor industry. For example, ITRI facilitated technical cooperation with domestic private enterprises for development of key technologies, as well as training highly qualified personal, expanding research links with institutions abroad and maintaining close relations between various universities and R&D organizations within Taiwan.[5] While the Taiwanese State directed these public research institutes to train a high-skilled workforce and other initiatives, the relative success of the personal and firms they create cannot solely be attributed to Taiwan's government policy. One must take a closer look at the national, educational and professional backgrounds of the individual actors and their personal networks before offering conclusions regarding the impact of State directives.

Additionally, Breznitz credits state attention towards building a local supplier network of firms for MNC's as a major reason for Taiwan's successful assimilation into the larger global IT ecosystem.[6] In other words, Breznitz gives credit to the State for encouraging firms to carve specialized niches in the IT and semiconductor supply chain, and integrating themselves into global supply chains. While true Taiwan developed a significant local supplier network for both domestic and foreign firms, did this development occur due to specific State policy actions, or

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[4] Dan Breznitz, *Innovation and the State*, 98.

[5] Walter Arnold, "Science and Technology Development in Taiwan and South Korea," *Asian Survey* (1988): 447.

[6] Dan Breznitz, *Innovation and the State*, 100.

did individual firms and personal's recognition of industry trends, like vertical disintegration of production, spawn the influx of specialized component producers? While Taiwan's semiconductor industry had a large local supplier network, Breznitz' claim overlooks the potential relevance of individual engineers, CEOs, and founders of the large local supplier network developing both local and global industry networks for knowledge transfer, thereby spurring innovation.

Breznitz claims Taiwan's public research institutes helped to form the strategy of basing Taiwan's semiconductor industry off achieving capabilities to modularly produce chips—instead of focusing on more capital-intensive memory chip markets, which at the time faced intense competition from high tech-giants; the U.S, Japan, and Korea.[7] Significantly, Breznitz mentions that these policy decisions are largely influenced by American advisors with the United States Department for International Aid (USAID). These advisors recognized global business trends of outsourcing and de-verticalization of organized production, which globalization catalyzed, and sought to create an industry in Taiwan to complement these global trends, while at the same time providing massive benefits for entrenched firms of advanced industrial nations, like the United States. Breznitz also claims the result of these initial policy directives, and other State provided inputs, like physical infrastructure, initial capital investments and education, led to the early success of State spinoff UMC as well as later leading to ERSO privatizing the construction of a "VLSI fabrication facility employing an innovative business model—the pureplay foundry."[8] Breznitz also points to successful semiconductor foundry firms—Vanguard and Winbond, who

[7] Dan Breznitz, *Innovation and the State*, 109.

[8] Ibid., 110.

were spin-offs of public domain projects—as additional evidence to support his claim of the State's central role in developing the industry.[9]

A criticism of Breznitz and others' claims of the central role of the State in Taiwan's high-tech semiconductor development is the literature of absorptive capacity. Absorptive capacity is defined as a firms ability to absorb knowledge and produce innovative products with ideas accessed through shared knowledge pools.[10] Political-economist Anthony Howell argues that high levels of state intervention has a negative relationship with domestic firms absorptive capacity.[11] Howell continues by claiming specifically State-led and top-down policy initiatives tend to result in issues of group-think; causing inefficient repetition of ideas and reducing outside-the-box and risk taking behavior that typically characterizes innovative activity.[12] Perhaps this criticism of Breznitz' argument suggests his emphasis on the State transitioning its role from active leader, to a decentralized supportive role, is a response to Howell and others points around absorptive capacity. Additionally, the well-documented cases of developmental state economies in Korea and Japan provide counter-evidence that high levels of State involvement in economic development decisions reduce innovation and successful high-tech catching up.[13]

Douglas Fuller in his article "The Cross-Strait Economic Relationship's impact on Development in Taiwan and China: Adversaries and Partners" explores the dynamic and

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[9] Dan Breznitz, *Innovation and the State*, 110.

[10] Cohen and Levinthal, 1990.

[11] Anthony Howell, "Relatedness economies, absorptive capacity, and economic catch-up: firmlevel evidence from China," *Industrial and Corporate Change (*2019): 3.

[12]Anthony Howell, "Relatedness economies, absorptive capacity, and economic catch-up: firmlevel evidence from China," *Industrial and Corporate Change (*2019): 4.

[13] Daedrick and Kraemer (2002).

changing cross-strait economic relationship—with a specific focus on the impact to Taiwan's electronics sector including semiconductors. Fuller largely concurs with Breznitz that State policy facilitated the acquisition of necessary inputs for the inception and initial 'start-up' phase of the industry.[14] However, significantly he states "although the Taiwanese State originally created both TSMC and UMC, the continued competitiveness of its semiconductor fabrication has had little to do with government policy beyond preferential tax treatment."[15] Fuller points to other forward looking State-policy methods, like the recruitment of MNC R&D centers to Taiwan, as one factor helping Taiwan maintain a competitive advantage in high-tech manufacturing.[16] Additionally, similar to Breznitz, Fuller credits entrenched and efficient communicative links between Taiwanese local suppliers and leading domestic firms. These industry networks represent significant barriers to entry for late-coming firms in other emerging economies without access to Taiwan's diverse local component supplier network, like China. Despite Fuller crediting the importance of industry connections, Fuller continues by largely crediting Breznitz' theory of ITRI model of technological upgrading within the semiconductor industry, as well as other successful Taiwanese tech industries, like automotive.

Network Driven Development in Taiwan's Semiconductor Industry

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[14] Douglas, Fuller, "The Cross-Strait Economic Relationship's Impact on Development," in *Taiwan and China: Adversaries and Partners*, *Asian Survey* 48 (2008), 252.

[15]Ibid., 252.

[16] Ibid., 255.

In the following section, we will discuss and analyze the arguments for a network-driven model of success stemming from the personal and professional networks of Taiwan's returnee entrepreneurs. Additionally, we will discuss technical factors contributing to the disintegration of vertical production and the creation of the fabless/fab model of semiconductor production. We will attempt to engage in a dialogue between State-driven and network driven arguments to understand whether or not the arguments are ultimately in contradiction with each-other.

Anna Lee Saxenian's book *The New Argonauts: Regional Advantage in a Global Economy* shifts away from an analytical focus on the role of the state, large corporations and domestic firms integration, replaced with analysis of global production networks for evaluating Taiwan's high-tech semiconductor industry growth.[17] While she recognizes State factors as supporting actors for high-tech development, her central claim is "entrepreneurs and their far-flung networks now play a vital role in the technology industries' global expansion—and make an increasingly important contribution to economic growth and development more broadly."[18] In the case of Taiwan, Saxenian claims while the public sector has played a role in the governance of the industrial system, "Taiwan's policymakers do not direct this process of technological and industrial upgrading, and institutions like ITRI and ERSO have limited control over the pace and direction of innovation in domestic industry."[19] Instead, Saxenian argues that ethnic Chinese U.S.- based engineers—due to shared bonds of cultural background, a diverse web of professional networks in cross-regional and local industry networks, as well as various public

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[17] Anna Lee Saxenian, "Taiwan as Silicon Sibling," in *The New Argonauts: Regional Advantage in a Global Economy,* (Cambridge: Harvard University Press, 2007), 130

[18] Anna Lee Saxenian, *The New Argonauts*, 100.

[19] Ibid., 132.

and private sector advisory committees and business associations assisting in networking events—facilitate the rapid diffusion of business and technical knowledge inputs necessary for producing at the innovative edge. In other words, by accessing accumulated industry knowledge sources, key individuals and expertise—such as the advantage of specialization in a volatile and technological uncertain environment— Taiwan positioned the domestic semiconductor industry for rapid success.[20] While Breznitz mentions the influence of "American advisors" when guiding ERSOs development decisions for the privatization of VLSI technology, he mainly focuses on the fact the decision comes from within the public sector. He does not offer a complex account of key actors backgrounds and connections within public sector institutions, which Saxenian suggests come closer to identifying the source for the dynamic shift in organized industrial production occurring in Taiwan's semiconductor industry.

Clair Brown and Greg Linden, in their book *Chips and Change: How Crisis Reshapes the Semiconductor Industry*, offer an alternative perspective to Taiwan's semiconductor success. Their analytical approach is based on the technical factors that lead to the industry wide re-organization of production, i.e. vertical disintegration. The authors discuss two main technical innovations that allowed for the breaking off between design and manufacturing: the digitization and transmission of design—perfected during early 1980s specifically with the Berekely Transistor Simulation Model (BSIM) —which allowed for design (fabless) firms to effectively transmit their chip designs to foundry firms located on the other side of the Pacific— as well as the solidification of the Metal Oxide Semiconductor (CMOS) process as the mainstream method of fabrication technology, which created a "predictable technology trajectory for designers to

[20] Ibid., 133.

target."[21] As a result of these technical innovations, it became profitable for vertically integrated firms to begin outsourcing more capital intensive stages of production, like physical fabrication, to the emerging semiconductor foundry sector. Additionally, advanced fabless design firms no longer feared outsourcing their innovative chip designs to the foundry firms due to foundry firms inability to take the designs and develop their own chip designs based off their customers. In other words, the de-verticalizaiton of industry reduced intellectual property disputes for fabless designers as they were no longer forced to turn to their competitors (large integrated IC firms) for the fabrication of their chip. When focusing our analysis, we must look closely at whether Taiwan's pureplay-foundry sector grew out of these technical innovations, or grew in anticipation of them.

Brown and Linden also discuss important characteristics of the semiconductor industry such as the level of the semiconductor industry's interconnectedness, even between different aspects of technological development. While semiconductor fabrication is itself an industry, pureplay-foundry firms heavily rely on separate technological advancement such as advancing lithographic capabilities. In fact, 20% of the cost to produce a cutting edge foundry is the price of lithography tools and equipment for fabrication.[22] This dynamic highlights the importance of developing cross-industry connections to different aspects of the supply and value chain, which also supports Saxenian's network-model approach for development.

Sue Ching Joe and Dung-Sheng Chen in their journal article "Keeping the high-tech region open and dynamic: the organizational networks of Taiwan's integrated circuit industry"

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[21] Clair Brown and Greg Linden, *Chips and Change*, 47.

[22] Clair Brown and Greg Linden, *Chips and Change*, 40.

explore the relevance of both domestic and external industry links that provide "channels for companies to gain market information, customers, technology, and capital."[23] The authors gathered empirical evidence by collecting data on the top 32 IC firms in the Hsinchu Science and Industry Park region and identifying key actions taken by these firms that had an impact on organizational development.[24] These "organizational events" occur both intra-firm, inter-firm and firm to external groups like trade associations. This paper adds a layer of support for Saxenian's argument on the central importance of network-led development. Significantly, the number of organizational connections increased rapidly during the late 80s and 90s, when private firms began to lead the semiconductor industry. Although this paper specifically mentions the important role ITRI and ERSO held during the early stages of semiconductor development, the number of events dramatically increased when these organizations were no longer as relevant. Additionally, this paper highlights the importance of having both regional and global cross-industry connections as over 50% of these 'organizational events' occurred within Taiwan. The concentration of events in the U.S.A is notable because it supports Saxenian's claim that specifically U.S. based ethnically Chinese engineers play a prominent role in the diffusion of knowledge to Taiwanese industry.

Table 1. Organizational connections by country and by year.

Year	Taiwan	U.S.A.	Japan	Europe	Others	Total
1976–80	1	2				3
1981–85	4	4	6			8
1986–90	55	32	10	4	3	104
1991–95	128	72	27	7	10	244
1996	36	24	3	2	5	70
Total	224	134	40	13	18	429
(percent)	(52.2%)	(31.2%)	(9.3%)	(3.1%)	(4.2%)	(100%)

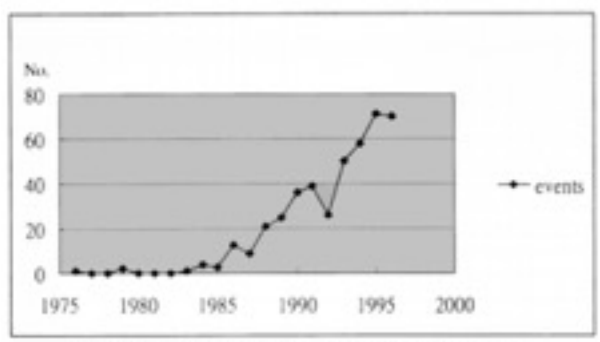

Figure 1. Frequency distribution of organizational relations for Taiwan's IC industry.

Jou, Sue-Ching, and Dung-Sheng Chen. "Keeping the High-Tech Region Open and Dynamic: the Organizational Networks of Taiwan's Integrated

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[23] Sue-Ching, Joe and Dung-Sheng Chen. "Keeping the High-Tech Region Open and Dynamic: the Organizational Networks of Taiwan's Integrated Circuit Industry," *GeoJournal 53*, (2001): 81.

[24] Sue-Ching, Joe and Dung-Sheng Chen. "Keeping the High-Tech Region Open and Dynamic: (2001): 82.

Breznitz may disagree with Saxenian's emphasis on individual entrepreneurs and their professional networks primarily contributing to the development of Taiwan's semiconductor industry because how can a network-centered approach explain the different development trajectories of Taiwan's hardware and software industries, which he claims is due to differences in the bureaucratic structures of public research consortia like ITRI and the Institution for Information Industry. Breznitz claims III's agendas—to promote Taiwan's software industry while also generating enough revenue to cover its own expenses—proved to be in conflict, with the end result that III has been competing directly with (Taiwan's) private software firms.[25] Additionally, he suggests "because III had captured the big governmental contracts, and the big global IT industries were competing directly on big projects, the industry was unable to develop big software houses specializing in customized development."[26] In response, Saxenian may suggest that by encouraging III to reach profitability, while also giving the institution generous government contracts and other benefits, the government policy aims to create a "national champion" rather than the "natural champion" approach seen in the semiconductor industry. Additionally, Saxenian may also suggest the issue is not a result of state policy creating conflicting agendas within a public research consortia, but instead is a failure to catalyze cross-regional connections. Owing to III's setting an industry direction to directly compete with top foreign software firms, this disincentives foreign firms to contract out higher value added activities with sensitive intellectual property information. If firms are attempting to directly compete, rather than complement, the existing software industry within advanced industrial

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[25] Dan Breznitz, *Innovation and the State*, 131.

[26] Ibid., 131.

economies, then it is likely to create a cooling effect on Taiwan's domestic industry cooperation with foreign firms. In other words, while good state policy can aid indigenous development of high-tech innovation, poor state policy derails indigenous development by interrupting the mutual positive feedback loop associated with carving a niche in the global division of labor, which results from connecting innovative and global leading firms with complementary secondary innovators. Due to less global industry interaction with Taiwan's domestic firms, Saxenian may suggest her brain circulating cross-regional networks are put on freeze due to intense local and global competition.

Breznitz is not alone in placing the central credit for Taiwan's semiconductor success in the hands of State technocrats. In Mathew's and Cho's article " A Silicon Valley of the East" and again in their book "Tiger Technologies" in terms of successful high-tech development, they largely credits Taiwan's technocrat in chief Premier Y. S. Sun and his recruiting efforts in the 70s of ethnic Chinese engineers in leading positions within U.S firms to make up the personal of the Technical Advisory Committee (TAC), as well as later on the Science and Technology Advisory Group (STAG). He claims the TAC framed recommendations for starting a new semiconductor industry within Taiwan, under the auspices of ITRI, which lead to the creation of ERSO and that organizations agenda for developing "the technological capabilities needed to generate a semiconductor industry."[27] Cho and Mathews continue by claiming ERSO's technological development and initial public sector capital expenditures led to successful technological upgrading, and eventual knowledge diffusion, into the local private industry.[28] He specifically

[27] Dong-Sung Cho and John Mathews, "A Cat Can Look at a King: How Taiwan Did it," in *Tiger Technologies: The Creation of a Semiconductor Industry in East Asia,* ed. John Ravenhill (Cambridge: Cambridge University Press), 159.

[28] Ibid., 164.

credits the TAC's recommendation for developing CMOS technology for fabrication as "a far-sighted decision given its subsequent significance as dominant semiconductor manufacturing technology.[29] Significantly, they mention that ERSO was unable to secure a foreign MNC for the initial technology acquisition of fabrication technology until "under the influence of Dr. Pan, then working for the US electronics firm RCA, ERSO was successful in signing a technology transfer agreement with RCA."[30] While Mathews and Cho seem to give credit to Dr. Pan, he does not open his analytical approach to account for the significance of Dr. Pan's professional connections to RCA and the global semiconductor industry in regards to ERSO's initial technology acquisition. Saxenian may suggest without key individuals private networks, it's difficult to determine whether any of ERSO's acquisition initiatives would have left initial planning.

Mathews and Cho credit STAG as well as the National Science Council (NSC) specifically for recommending the creation of the Hsinchu Science Park, which has historically played the role of intra-industry and inter-firm connector, as well as continues today to house Taiwan's most advanced semiconductor and IC firms. Funding for the HSP was largely State provided, and soon after completion pubic consortia, like ERSO and ITRI, located their development initiatives in the park. Significantly, Cho fails to mention that all 15 of STAG were recruited from the United States, where technology based clusters like Silicon Valley were already the predominant and preferred method of industrial spatial-organization.[31] Essentially, Saxenian suggests that although these important policy decisions facilitated key developments in

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[29] Ibid., 164.

[30] Dong-Sung Cho and John Mathews, *Tiger Technologies,* 165.

[31] Anna Lee Saxenian, *The New Argonauts*, 143.

the upgrading of Taiwan's semiconductor technology, “reliance on U.S.-based engineers for technical and managerial experience and policy advice fundamentally shaped the direction and pace of Taiwan's technology development.”[32] In other words, while the policy decisions came from within the public sector, in reality a network-based model for development—seen through the STAG and TAC members professional backgrounds and networks— lead to the insightful and far-reaching policy decisions of Taiwan’s public research consortia and leading technocrats.

The proposal for the HSP was part of a larger initiative to attract foreign investment in Taiwan’s research-oriented companies, but at first the park failed to attract large MNCs industry activity. Despite the park serving as “a high-technology version of an export-processing-zone, one that offered subsidized land and financial incentives for R&D intensive manufacturing tenants,” technology-intensive R&D firms were not persuaded to move their high-tech manufacturing operations to the park.[33] Taiwan’s bureaucrats sought out a different method of catalyzing development in the park, and did so by promoting the introduction of private venture capital firms to Taiwan. Saxenian may suggest without changes in the financial regulatory structure—-Taiwan historically restricted financial decisions based off a patriarchal system where family members closely controlled businesses financial affairs—as well as without initial State-led efforts to recruit senior Chinese-American financiers to establish VC firms in Taiwan, then the Hscinchu Science Park may not have succeeded in becoming “an open laboratory for the growth of indigenous technology firms.[34]

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[32] Ibid., 143.

[33] Anna Lee Saxenian, *The New Argonauts*, 144.

[34] Ibid., 147.

Breznitz also credits the introduction of private VC firms as an important factor supplying the capital necessary for launching semiconductor firms and enhancing these firms R&D capabilities. However, he diverges from Saxenian by claiming "Li's and subsequent government initiatives have taken great care to make sure the Taiwanese VC industry stays Taiwanese, devoting all their attention to motivating local investor participation."[35] While Saxenian admits much of the financing for Taiwan's initial VC firms came from within existing Taiwanese industry, she would also highlight the significant impact of U.S.-educated overseas Chinese engineers, like Peter Liu and Lip-Bu Tan, who established Taiwan's second U.S.-style venture fund, the Walden International Investment Group."[36] Significantly, Saxenian and Breznitz again diverge on the role and impact of State regulatory decisions, pertaining finance and financial options, in regard to employee stock-options, designed to attract and maintain high-value talent.

Breznitz argues that owing to the structure of Taiwan's financial regulations, which only allows employee stock options for firms who are already public, the structure incentivizes top engineering talent to enter the employment of entrenched firms like TSMC and UMC. In turn, this reduces the flow of top IT engineering talent towards smaller firms with more specialized and riskier development strategies; thereby reducing first-generation technology innovation.[37] Saxenian may agree that these policies create a fast-track for engineers to enter Taiwan's top firms, but simultaneously these favorable financial policies, which also include the elimination of any capital gains tax, resulted in a massive influx of ethnic returnee engineers and

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[35] Dan Breznitz, *Innovation and the State*, 141.

[36] Anna Lee Saxenian, *The New Argonauts*, 147.

[37] Dan Breznitz, *Innovation and the State*, 140.

entrepreneurs.[38] Oftentimes these returnees enter an entrenched pureplay- foundry model firm like TSMC or UMC, and after earning significant profits, leaves to create a new firm or become part of a spin-off firm that continues to carve out niches in a global division of secondary-generation complementary technology. While Breznitz is concerned that the structure of this financial incentive system will reduce the likelihood of Taiwanese firms developing first-generation technologies, Saxenian suggests that attracting the most talented engineers and bringing the most advanced human capital to Taiwan will result in a continuous process of firms finding new niches in the global division of labor. In fact, returnees made up 42% of the positions on founding teams for firms located in the Hsinchu Science Park in 2000.[39] In other words, while these firms may act as complements to existing innovative industry in high-tech economies of advanced industrial nations, they continue to enhance the overall economies technological level.

Conclusions

Breznitz vision of the 'Innovation State' and Saxenian's account of returnee entrepreneur network-led development are not in direct opposition to each other. Both authors recognize similar trends and factors leading to the development of Taiwan's semiconductor pureplay-foundry sector, but they fail to cohesively connect their complementary narratives. Taiwanese State institutions, like ITRI, ERSO, NSC, TAC, and STAG as well as State financial policies,

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[38] Anna Lee Saxenian, *The New Argonauts*, 149.

[39] Anna Lee Saxenian, *The New Argonauts*, 150.

regarding venture capital and the financial regulatory structure, undoubtedly facilitated the development of Taiwan's semiconductor industry and continues to hold nominal levels of development decision making power. However, these institutions and policies alone are incapable of offering a complete picture of Taiwan's semiconductor industry success.

Additionally, U.S-educated Taiwanese entrepreneurs, like Morris Chang, Dr. Wen Yuan Pan and Dr. Ding-Yuan Yang, as well as others in key positions within Taiwan's technocratic class, provided industry expertise, connections and know-how from the leading semiconductor and IT firms to Taiwan's domestic industry. Without these entrepreneurs Taiwan's semiconductor development would have gone without managerial and technical expert guidance, as well as policy advice. Additionally, without the connections to IT and semiconductor firms to the United States, which the U.S-based engineers brought with them, then Taiwan's semiconductor industry would have struggled to integrate themselves into a complementary position within the global division of labor.

Breznitz is correct that State policy deserves credit for Taiwan's semiconductor development, but he does not accurately depict the reasons why State policy was successful. Taiwan's State policy aimed to expand their technological level within semiconductor manufacturing by actively targeting Saxenian's network-led model of development. Likewise, these returnee entrepreneurs and their networks aided Taiwan's government facilitating the development of the semiconductor industry from within the public sector. Neither State industrial policy nor Saxenian's network of transnational elites could accomplish the striking success of Taiwan's semiconductor industry without the other. Despite this fact, there are differences between some of Taiwan's top semiconductor firms that are a product of different development

influences. Some of Taiwan's domestic firms have origins stemming from the state, some have semi-state origins and others have completely private VC origins. Although both Breznitz and Saxenian's development explanations are complementary and unable to exist without the other, one may suspect differences in terms of the ability for a firm to produce at the cutting technological edge in relationship with the firm origins. The next chapter will first look at the timing of Taiwan's key policy initiatives and decisions in relation to domestic firms development decisions and global outsourcing and de-verticalization trends, as well as evaluate the direct impact of these decisions on both Taiwan's semiconductor industry as a whole, as well as a few key semiconductor firms within Taiwan.

Chapter 2

State-Driven Innovation in Taiwan's Semiconductor Industry

Our discussion will now turn to the State public research consortia, policy initiatives, advisory groups, and other public inputs Breznitz, Mathews and Cho, Fuller and others point to as drivers of Taiwan's semiconductor advancement. We will discuss how certain State-led actions helped forge a path forward for Taiwan's semiconductor industry, as well as actions supporting the relationships, incentives and other public inputs necessary for foreign technological acquisition and domestic technological upgrading. Finally, we will focus our analysis on how certain State-oriented actions impacted firms with state, semi-state and non-state origins development decisions within the pureplay- foundry semiconductor sector, firms which other

scholars like Breznitz and Saxenian target as a topic for empirical analysis. To provide the reader with a better understanding of Taiwan's domestic industry and the history of State driven development, we will begin the chapter with a brief historical background of Taiwan.

Historical Context for the Development of the Modern Taiwan State

As discussed previously, Breznitz' state-driven argument is largely founded in a vast literature describing the developmental state. Additionally, Taiwan's specific historical context, even before the Kuomintang rise to power in 1949, has largely been a result of layers of heavy-handed government industrial policy. Under Japanese occupation, there were efforts to transform the colony into a modern state; "Japanese colonialists introduced what were at the time modern railways, a modern telephone and communications grid, a modern banking system, a highly developed commercial market network, an effective public health system…even more important was the expansion of literacy and technical training."[40] Following occupation, Taiwan essentially operated under the undivided authority of Jiang Jieshi who achieved unity, though by objectionable methods, which allowed modernizing bureaucrats more room to maneuver in promoting industrialization and "gave capitalists confidence in the security of their investment in Taiwan's industry."[41] During the first 30-40 years of Taiwan's development, Economic planning remained firmly in control of the State, as well as within foreign allied development institutions like USAID. In addition to serving traditional government roles like macroeconomic monetary

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[40] Ezra Vogel, "Taiwan," in *The Four Little Dragons: The Spread of Industrialization in East Asia*, (Cambridge: Harvard University Press, 1991), 20.

[41] Ibid., 18.

and fiscal policy decisions, Taiwan's prominent technocrats K. T. Li and K. Y. Lin, "believed in the important role of government in helping to acquire technology, allocate funds for key projects, and guide the development of the economy."[42] These bureaucrats were observers of their fellow East Asian late developers and utilized similar protectionist policies quite common within developmental states. Some example policies included protection of infant industries from foreign competition, limiting the extent of foreign control in Taiwanese business, implementing component requirements for firms intending to sell within Taiwan's domestic market, as well as targeting sectors with growing wage demands within developed economies.[43]

Catalyzing Taiwan's industrial development resulted in the creation of new state firms in key areas such as steel, shipbuilding, electric power and nuclear power. While private industry slowly was integrated into the system, the government largely held a monopoly over the availability of credit, and had a large impact on picking the winners of development projects.[44] Significantly, the Taiwanese financial system—which limits patient capital—is in stark contrast to Gerschenkron and the developmental state models, which emphasize the need for capital rich long-term loans often coming from the State.[45] Essentially, the State took responsibility and control over the upgrading of basic upstream industries, as well as infrastructure, in order to supply the necessary inputs for private industry to thrive. This determination to protect Taiwan's infant industries, introduce new technologies, and minimize foreign investment helped local

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[42] Ibid., 27.

[43] Dan Breznitz, *Innovation and the State*, 103.

[44] Ezra Vogel, *The Four Little Dragons*, 31.

[45] Gerschenkron, 1962.

firms gain strength and avoid displacement by foreign MNCs.[46] For much of Taiwan's early development, Taiwan followed a slightly deviated developmental state model and filled a lead role in guiding development decisions, as well as providing the necessary inputs for domestic firms to succeed. With an understanding of Taiwan's historical context, one can understand why Breznitz's analysis of Taiwan's high-tech semiconductor manufacturing industry tends to continue to view development primarily through the lens of State institutions and policies.

The initial arrival of the semiconductor industry in Taiwan started when foreign firms began to outsource testing and assembly stages of production during the 1960s.[47] At that time Taiwan's labor wage rates were significantly lower than the advanced industrialist economies. Low wages combined with the stability of strong KMT rule meant for MNCs Taiwan was an attractive nation to locate production. Additionally, Taiwan created the first Export Processing Zone (EPZ) which offered tax incentives and eased labor regulations for foreign firms. As a result a few U.S. semiconductor firms to moved their test and assembly stages of production to Taiwan. While generally the EPZ should be considered a success, as it provided employment opportunities for Taiwanese, assembly and testing stages of production does not require sophisticated manufacturing technology; therefore, the EPZ was unsuccessful in upgrading Taiwan's technological level.[48]

The 1970s brought many major shocks to the established global order and it was during this period that Taiwan's bureaucrats began initiatives for major industrial and technological

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[46] Ezra Vogel, *The Four Little Dragons*, 28.

[47] Hong Sul, "Why Differ? Taiwan and South Korea Compared," in *The Political Economy of Industrial Policy in East Asia: The Semiconductor Industry in Taiwan and South Korea,* (Cheltenham: Edward Elgar Pub, 1997), 46.

[48] Ibid., 47.

upgrading. While not directly connected to Taiwan's plan for establishing more high-tech industries, the fall of the Bretton Woods System, the Oil Shock of 1973, increasing neo-protectionist measures from advanced industrial economies and rising competition from other low-cost labor economies made it clear to Taiwan's bureaucrats that maintaining an economy located in low-value added segments of the supply chain was increasingly unsustainable.[49] Some scholars have argued it was Taiwan's unique response to the economic challenges in the 70s that differentiated the developmental style from similar late-developers such as Korea. The State's response to these challenges in the 70s marks the beginning of our analysis, which focuses on the role of Taiwan's government in the remarkable success of the semiconductor fabrication industry.

State Policies and Semiconductor Initiatives

Our discussion will now turn to the State public research consortia, policy initiatives, advisory groups, and other public inputs Breznitz, Cho, Fuller and others point to as drivers of Taiwan's semiconductor advancement. We will discuss how certain State-led actions helped forge a path forward for Taiwan's semiconductor industry, as well as actions supporting the relationships, incentives and other public inputs necessary for foreign technological acquisition and domestic technological upgrading. Finally, we will focus our analysis on how certain State-oriented actions impacted firms with state, semi-state and non-state origins development decisions within the pureplay- foundry semiconductor sector, firms which other scholars like Breznitz and Saxenian target as a topic for empirical analysis.

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[49] Hong Sul, *The Political Economy of Industrial Policy in East Asia,* 47.

Breznitz and others like Hong Sul claim that Taiwan's public research consortia, ERSO and ITRI, led the fledgling semiconductor industry forward when capital sources were limited and technological levels low. The literature universally points to the meeting of Dr. Y.H Sun and Dr. Wen-yuan Pan, in August 1974, as a crucial starting point for the inception of these consortia.[50] Initially, as a result of the meeting, the organization ITRI was created. ITRI became a central supporter of foreign technology acquisition for the first steps of Taiwan's semiconductor industry development. Interestingly, rather than selecting prominent State bureaucrats to lead the push into high-tech electronics, Sun targeted ethnic Chinese engineers working in the U.S to lead the push into the semiconductor industry and placed them in key positions within Technical Advisory Commitee. The structure of the State policy, specifically the makeup of the TAC, suggests attempts to incorporate the connections of these engineers within the policy decision process. The TAC recommended ERSO's creation in 1974 "whose head was immediately charged with the task of developing the technological capabilities needed to generate a semiconductor industry."[51] ERSO successfully found a leading edge firm in RCA, which willingly transferred their abandoned and out-of-date 7-micron CMOS semiconductor fabrication technology.

According to Cho, when the TAC prepared a report for the Taiwan cabinet on their proposal to create a semiconductor industry, one of the requests was "CMOS was to be the technology of choice."[52] Although CMOS technology was invented in 1963 by Frank Winless, CMOS technology did not become mainstream until the introduction of the 256Kb CMOS

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[50] Dan Breznitz, *Innovation and the State,* 104.

[51] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 158.

[52] Ibid., 164.

DRAM in 1984, which followed the decision of ERSO to focus developing CMOS process technology.[53] Mathews and Cho argue "the capacity to 'read' technological trajectories provides one of the critical points of leverage that latecomers need in order to effect entry."[54] This decision was not based off of any 'latecomer' advantages as Gerschenkron may suggest, but instead was the direct result of a forward-looking State. Without this favorable technical decision, one may argue the State's attempt to create an indigenous semiconductor fabrication industry would not have achieved the same level of success. While this decision was done by State institutions, and later followed by the private industry, without the structure of the policy making institutions being heavily influenced by the U.S- based Taiwanese engineers, such as Dr. Wen-Yuan Pan, RCA may not have transferred any CMOS technology and Taiwan's technical edge may have diminished.

ITRI and ERSO's agreement with RCA proved to be a watershed moment for Taiwan's semiconductor industry. RCA agreed to train forty of Taiwan's top young engineers, many of them graduates of U.S engineering higher education institutions, in wafer processes, design and chip manufacturing.[55] Following training, the engineers returned to ERSO and ITRI helping advance the organizations semiconductor processes from 7 to 4.5 micron technology. With RCA's technology and know-how transfer, ERSO successfully spun-off the public semiconductor development project into a private-public partnership to form the firm United Microelectronics (UMC). These engineers continued to play a central role in Taiwan's remarkable semiconductor

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[53] International Roadmap for Devices and Systems, "Beyond CMOS: the Future of Semiconductors, What is Beyond CMOS," https://irds.ieee.org/home/what-is-beyond-cmos.

[54] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 75.

[55] Ibid., 165.

success. Many of them, including Tsai Ming-Kai now CEO of MediaTek, after working within the public consortia left to join State spinoff firms like UMC or TSMC, and then later founded or joined Taiwan's rising private semiconductor firms in the late 80s and 90s.

Breznitz and Cho both suggest that State institutions like ERSO not only aided Taiwan's technological upgrading by acting as a diffuser of foreign technology, but also served as a focal point for Taiwanese innovation. This was especially true for the successful State spinoffs of UMC and TSMC. Following ERSO's initial technology acquisition and technical training with RCA, the public consortia successfully and independently upgraded their micron technology and aimed to commercialize this upgrade by forming a public-private company.[56] In addition to receiving all its technical staff and technology directly from ERSO, UMC was also granted technical assistance from, and the use of, ERSO's fabrication plant.[57] Without ERSO's support, UMC's acquisition of technical talent (human capital) would have remained a challenge for the fledgling firm. The challenge was to then raise the initial capital requirement for commercializing ERSO's fabrication technology. Without the capital provided by the ministry of economic affairs (MoEA), UMC's capital sources would have been insufficient due to a reticent private capital sector.[58]

While the founding of UMC put Taiwan's semiconductor firmly integrated within the global semiconductor industry, the introduction of TSMC and the pureplay-foundry model revolutionized the entire industry and resulted in Taiwan's top firms carving out market massive niches at the high-tech manufacturing level of production. Following the success of UMC, in

[56] Dan Breznitz, *Innovation and the State,* 106.

[57] Ibid., 107.

[58] Ibid., 107.

1981 the Science and Technological Advisory Group and specifically President and Premier Sun, aggressively pushed the advancement of Taiwan's VLSI capabilities to one micron level by 1988.[59] After some back and forth between ERSO and UMC over where the fabrication facility project should go, the State decided to designate ERSO as the entity charged with the project in order to avoid an over concentration of power in a single private firm.[60] At this point, Taiwan's public research consortia continued to lead the way for domestic industry by providing advanced research and development for designs processes and technologies. However, as semiconductor design capabilities increased it became more and more evident that the lack of fabrication manufacturing facilities forced Taiwanese semiconductor design firms to contract manufacturing to third party manufactures, who were also potential competitors at the design stage of production. For example, part of ERSO's VLSI project was the development of DRAM chip designs, and ERSO pursued a joint-venture strategy with ethnic Chinese Silicon Valley design firm Vitelic. The project successfully designed a DRAM chip but then Vitelic sold the designs to the Korean firm Hyundai, a project partially funded by the State, which caused rising concerns that despite technological advancement Taiwanese firms would not fully capitalize on the Industry's increasing capabilities to generate high-tech intellectual property.[61] In an effort to provide advanced manufacturing facilities for Taiwan's rising design firms, in 1985 ITRI recruited Morris Chang, then CEO of General Instruments, to serve as president of the institution. Significantly, "instead of proposing a conventional semiconductor company with its

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[59] Dong-Sung Cho and John Mathews, *Tiger Technologies,* 169.

[60] Dan Breznitz, *Innovation and the State,* 109.

[61] Ibid., 109.

own product portfolio, Chang advocated for pure-play 'silicon foundry' operating VLSI process technology to manufacture chips for small Taiwanese firms and international clients."[62]

Raising the initial capital investment for the spin-off project, TSMC, was not an easy task. Premier Yu at the time stipulated that the project must not be entirely financed by the government in order to quicken the pace of private capital into Taiwan's semiconductor industry.[63] However, even in the 1980s the cost of building an advanced manufacturing facility and the unattractive risk-return tradeoffs made it improbable that private capital would back such a project.[64] Breaking with Taiwanese conservative views of foreign direct investment, ITRI again pursued a MNC joint-venture partner and eventually found one in the Dutch MNC Phillips. The capital from Phillips gave them a 27.5% equity stake in TSMC, with another 48.3 % of the investment coming from an investment arm of the KMT party, the China Development Corporation.[65] The State provided initial R&D, finance and human capital as many of ITRI's engineers, including Morris Chang, left to join the new spinoff company TSMC. Significantly, TSMC and Phillips signed a cross-licensing agreement allowing TSMC the use of Phillips 2 and 1.5 micron process technologies.[66] This agreement allowed TSMC to utilize Phillips advanced designs in their fabrication technology without risking potential legal liability. Following the arrival of TSMC, Taiwan's semiconductor industry rapidly expanded as private capital eventually

[62] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 170.

[63] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 171.

[64] Clair Brown and Greg Linden, *Chips and Change*, 43.

[65] Dan Breznitz, *Innovation and the State,* 111.

[66] Dong-Sung Cho and John Mathews, *Tiger Technologies,* 172.

recognized the potential for returns from Taiwan's new niche in the high-tech semiconductor global division of labor.

Many scholars argue the development of Taiwan's industry had three distinct phases: seeding, start-up, and expansion.[67] Jou and Chen's article "Keeping the High-tech region open and dynamic: the organizational networks of Taiwan's IC industry" focuses analysis on organizational events. These events are separated by the periods of Taiwan's high-tech development, and defined as actions taken by high-tech organizations which influenced firm organizational structure and development decisions.[68] Additionally, events were divided into categories of either technological, financial, or manufacturing. They suggest these events facilitated Taiwan's development of a vertically disintegrated agglomeration system in the Hsinchu Science Park region.[69] Specifically, during the seeding or infancy stage of Taiwan's high-tech development, the organizational events found by Jou and Chen's study were mostly organized by ITRI. Notedly, the location of these events were primarily in Taiwan and the United States, which indicates ITRI understands the importance of and facilitated domestic firms simultaneously developing organizational relationships within Taiwan's highly disintegrated local producer network, as well as within global networks. Following the seeding stage of development, Taiwan's private firms began to participate in organizational events in large numbers. However, without the State's early attempts to connect domestic and global firms, as well as the successful spin-offs of UMC and TSMC, these private firms would have lacked clear

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[67] Jou, Sue-Ching, and Dung-Sheng Chen. "Keeping the High-tech Region Open and Dynamic: The Organizational Networks of Taiwan's Integrated Circuit Industry." GeoJournal 53, no. 1 (2001): 83.

[68] Ibid., 82.

[69] Ibid., 82.

examples for potential returns owing to these industry interactions, and as a result may have pursued a different expansion strategy.

Taiwan's government is largely responsible for launching Taiwan's semiconductor industry primarily due to ERSO and ITRI's successful spin-off companies, TSMC and UMC, which are now the pureplay-foundry leaders within Taiwan and compete against other leading global firms like Intel, Samsung and Texas Instruments. State technocrats and groups like the TAC and STAG took the first steps towards supporting global and domestic information exchange by placing ethnic Chinese engineers with experience in the U.S. industry as key decision makers within public institutions. The State circumvented private capital's reticence to invest in Taiwan's fledgling high-tech semiconductor industry by providing public R&D spending, public capital as well as human capital support for creating the spin-off companies TSMC and UMC. Without these initial State-led efforts to establish the semiconductor industry, where technocrats led prescient decisions to pursue CMOS processing technology, as well as avoid over concentration of industry activity within a single national champion firm, then Taiwan's semiconductor industry would likely not have achieved such a high level of success.

Public Inputs Supporting Cross Cultural and Cross-Industry Communication

The State's impact over Taiwan's semiconductor development trajectory did not begin or end with the successful spinoffs of ERSO and ITRI. In fact, many State directives were not directly connected to public R&D spending, guiding industry or firm level technical development decisions, and State capital injections (human, financial) directly into the domestic

industry. Additionally, as discussed briefly previously, State institutions, like ITRI and the HSIP, took an active role in establishing cross industry connections by opening offices in Silicon Valley and initiating the first 'organizational events' for Taiwan's semiconductor industry. Taiwan's government took a society wide approach by utilizing all the instruments at the State's disposal including providing tax benefits, as well as educational and industry infrastructure to incentivize and attract ethnic Chinese engineers from overseas. Not all government support comes in the form of direct involvement with industry.

A signature development of Taiwan's semiconductor industry was the creation of the Hsinchu Science Based Industrial Park (HSIP). Again, this policy came directly from State organizations, which in this case was the National Science Council (NSC). The HSIP is universally acknowledged as the center of Taiwan's innovative and high-tech activity. The park continues to favor firms with significant R&D operations, as the HSIP often matched firm's R&D levels, as well as gives special subsidies including tax holidays, exemption on equipment importation and commodity exports and low-interest loans.[70] Additionally, the park provides specialized infrastructure including housing and education for foreign-based engineers and their families.[71] The State sponsored upgrading of the educational infrastructure in the park, such as the creation the International Bilingual School at Hsinchu Science Park, is a clear example of State policy indirectly yet actively targeting these returnee entrepreneurs. The school is jointly overseen by the Ministry of Education and the National Science Council and offers courses taught in english, including American history, as well as offers Advanced Placement classes.

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[70] Dan Breznitz, *Innovation and the State*, 106.

[71] Ibid., 106.

Significantly, according to the schools website, recently the school has also included requirements for mandarin and Chinese cultural classes, which perhaps indicates China as an important location for expanding Taiwan's high-tech development. While the State created the park and provided the capital for the project, the idea for high-tech parks already existed, like Silicon Valley, albeit in a different form. The HSIP is a clear example of State policy attempting to mirror and catalyze a network-based model of development by creating attractive benefits for returnee entrepreneurs and their families.

Taiwan's technocrats often attempted to connect industry with local technical schools like National Taiwan University and National Tsing-Hua University. During ERSO's development of VLSI technology, the organization attempted to seed VLSI capabilities in Taiwan's technical schools by providing projects to professors and their students.[72] The National Science Council made significant financial commitments to semiconductor research with local universities, even despite some government opposition.[73] Additionally, the location of the HSIP as well as ITRI is in close proximity to National Taiwan University and National Tsing-Hua University. Significantly, the fact that the HSIP was deliberately located adjacent to top technical universities mirrors other high-tech clusters, like Silicon Valley. The HSIP not only emulates a Silicon Valley style of high-tech clustering, the HSIP as well as other public organizations like ITRI established offices in Silicon Valley where "they quickly built local industry organizations in order to monitor industrial and technical trends for domestic producers."[74] These organizations believed

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[72] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 170.

[73] Anna Lee Saxenian, *The New Argonauts*, 141.

[74] Ibid., 143.

that upgrading technologically on the domestic front meant fostering industry relationships abroad, specifically within the United States technical communities.

Taiwan's National Science Council has served an important and changing set roles in the development of Taiwan's semiconductor industry, including leading initiatives like the foundation of the HSIP. Following the derecognition of Taiwan's government by the United States, Japan and other Western government in the 1970s, "the NSC has remained in close touch with equivalent organizations in these countries, primarily through paradiplomatic channels."[75] Significantly, while the NSC played an important role in "the upgrading of Taiwan's industrial infrastructure," the organization must compete for funding with other S&T development organization such as the Industrial Development Bureau of the Ministry of Economic Affairs, the Council for Economic Planning and Development, the Ministry of Telecommunications and others all supporting various State sponsored R&D projects.[76] This unique decentralized infrastructure encouraged State support of basic research projects, that act as the foundation for the commercialized R&D of Taiwan's semiconductor industry, while also discouraging State consortia and institutions from over-prioritizing certain projects with closer connections to the State.

Taiwan's government utilized a range of policy tools and public inputs in order to attract MNC's as well as ethnic Chinese engineer returnees to Taiwan. While Taiwan offered generous tax benefits, capital injections, public R&D and favorable regulations, the State took also too a cumulative societal approach by emphasizing integrating industry with academia, providing

[75] Walter Arnold, "Science and Technology Development in Taiwan and South Korea," 445.

[76] Ibid., 445.

high-level educational opportunities for an international workforce, as well as creating the Hscinhu Science Park. In the next section, we will turn our focus to assess if these State policies significantly impacted both State spinoff, as well as private firms, development trajectories.

State Inputs Impacting Firm-level Development Decisions in State Spinoff and Private Firms

While the onslaught of global economic forces, as well as the fragmentation and vertical disintegration of production has severely reduced State's ability to direct development decisions, Taiwan's government, like any other, maintains responsibility for setting the regulations and benchmarks for the development of institutional structures. The structure of a system informs and shapes actors decisions within a system; therefore, the State retains a large degree of impact over industry because all industries rely on public sector institutional inputs. An often discussed unique Taiwanese State policy is the structure of the financial system. A system which limits patient capital discourages the formation of massive long-term focused capital intensive firms, while also encourages the development of small and medium sized enterprises focused on short term profits. Unlike comparable East Asian economies, Taiwan lacks massive corporate conglomerates, like the Korean *Chaebols* or Japanese *Keiretsu*, which in a sense prevents investment in capital intensive markets like the DRAM memory market.[77] Even within Taiwan's semiconductor manufacturing sector, which requires increasingly large R&D and capital investment, in 1993 only 68% of revenue from Taiwan's foundry market came from the top three

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[77] Hong Sul, *The Political Economy of Industrial Policy in East Asia,* 128.

firms compared to 96% concentration in Korea.[78] While the industry developed the concentration of revenue in Taiwan's top firms increased, Taiwan still maintains many small to medium sized IC design and select foundry firms. While one can argue that this is at least part due to the structure of Taiwan's financial system set up by Taiwan's conservative bureaucrats, the historical context of Taiwan also plays a significant role in determining the scale of business organization.[79]

Taiwan's medium to small sized semiconductor firms in part developed as a result of Taiwan's unique financial system, which reduced the amount of patient capital in circulation. As noted in the previous section, one of the main reasons the State decided to pursue fabrication capabilities was the result of Taiwan's smaller and medium sized firms having to give their designs to potential competitors in order to manufacture their product. With that said, without Taiwan's domestic producer environment, a system with large numbers of small to medium sized firms, perhaps the State would not have easily recognized the potential benefits of developing modular VLSI fabrication capabilities. More specifically, ITRI may not have pursued Morris Chang and the pureplay-foundry vision he advocated for.

These smaller-scale firms, like Winbond Electronics Corporation, are unable to compete with TSMC or UMC's successful economies of scale model of production. As a result, evidence supports the trend that companies are forced to specialize within small niches of the semiconductor industry's division of labor. Additionally, smaller firms, like VIS, that fail to specialize— investing heavily in R&D activities—results in lower rates of technological

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[78] Hong Sul, *The Political Economy of Industrial Policy in East Asia*, 130.

[79] Ibid., 133.

advancement, thereby disadvantaging the firm. When comparing TSMC and Winbond Electronics R&D to net income ratio from 2002 to 2005, one can clearly see that Winbond, a smaller as well as late-comer firm compared to TSMC, not only invests a higher percentage of their net income in R&D, but also invests at times up to 400% of their net income into R&D investments.[80] While Winbond still has a gap between firm level fabrication technological capabilities and the cutting edge of Taiwan's semiconductor pureplay-foundry sector TSMC, Winbond maintains a near identical rate of technological-advancement. Meanwhile, VIS has a lower percentage R&D to net income ratio than TSMC and achieved no significant technological advancement in fabrication technology during the same time. Owing to the structure of the State's bureaucratic and financial system, which structurally limits the concentration of industry power and favoring natural rather than national champions, results in Taiwan's semiconductor industry containing both large and medium sized firms. This structural difference, largely influenced by State development decisions, results in medium sized and or late arriving firms investing a disproportionate amount of firm net income into R&D. High levels of investment in R&D is an indicator for a firm's level of specialization. In other words, a unique characteristic of Taiwan's semiconductor industry development is the tendency for smaller and medium sized firms to specialize and carve out smaller and smaller niches within the semiconductor supply chain division of labor.

Sigficantly, Winbond Electronics is a firm that was not technically a State spinoff firm, but does have semi-state origins. Winbond's founder, Dr Ding Yuan Yang was the former head of ERSO's pilot semiconductor manufacturing facility as well as an alumni of the RCA 40. He, like

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[80] Integrated Circuit Engineering, "Winbond," 2002- 2006.
Ibid., "TSMC," 2002-2006.

many of Taiwan's most successful engineers, started his career in the United States and was recruited back to Taiwan to serve as the head of ERSO's fab. Dr Yang decided to leave ERSO on his own accord and found an investor in Walshin Lihaw Corporation, an original investor in UMC, and privatized ERSO's lab while also hiring may of the ERSO staff working at the fab.[81] Winbond's background with ERSO, where Winbond's very same engineers helped successfully spin-off UMC and TSMC, perhaps gave the new private firm a competitive edge as they were quickly able to acquire high-level technical talent from State sources.[82] While true, the semi-state origin of Winbond allowed the firm to pass over significant barriers to entry, other firms also successfully broke through barriers of entry without any State background, firms like Macronix International. Significantly, these private firms development decisions are still in part impacted by State inputs like the structure of the financial system.

Macronix (MXCI), founded in 1989, was one of the first semiconductor firms in Taiwan financed with venture capital. Macronix raised sufficient funds to establish a VLSI fab in the HSIP with advanced micron processes as well as hire over 40 Chinese-Americans with experience in the US semiconductor industry.[83] Macronix is another example of how Taiwan's semiconductor industry pursued intense specialization, resulting in competitive advantages and market niches. Macronix, similar to TSMC, aggressively pursued strategic technology alliances and joint-development strategies with large MNC's. Specifically, Macronix attempted to pursue DRAM memory chip fabrication technologies by partnering with leading Japanese and other MNC firms like, Matsushita Electric Industrial, not as a way to compete in the DRAM market,

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[81] Dong-Sung Cho and John Mathews, *Tiger Technologies,* 174.

[82] Ibid., 172.

[83] Ibid., 175-176.

but in order to build technological expertise and eventually offer specialized DRAM chip services.[84] It's a testament to the success of UMC and TSMC assuaging investors concerns that a firm with private capital origins was willing to enter such a capital-intensive and high-risk market like DRAM production. These partnerships, as well as high R&D to net income ratios 50% in 1999, 48% in 2004, 42% in 2006—- were significantly higher than TSMC during these same years—ultimately resulted in the firm maintaining relevance despite it's relatively small size compared to market leaders TSMC and Intel.[85] Regardless of firms origins, in order to remain competitive and carve out market niches, Taiwan's smaller to medium sized semiconductor fabrication firms generally maintain extremely high levels of R&D to net income ratios.

Notably, TSMC generally has significant lower levels of R&D to net income ratios compared to leading edge competitors Intel, Texas Instruments and Samsung. For example, in 2003 TSMC R&D to net income ratios was 33.465% while the combined average of Intel, Texas Instruments and Samsung was 92%; in 2005 TSMC R&D to net income ratio was 14.3% while the combined average of Intel, Texas Instruments and Samsung was 63.8%.[86] The data suggests in order to remain competitive at the cutting edge, even large firms with successful economies of scale invest heavily in R&D. Significantly, the large gap between TSMC and it's competitors may be a result of the data not differentiating between types of R&D within the Intel, Texas

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[84] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 177.

[85] Integrated Circuit Engineering, "Macronix International," 1999, 2002, 2006.

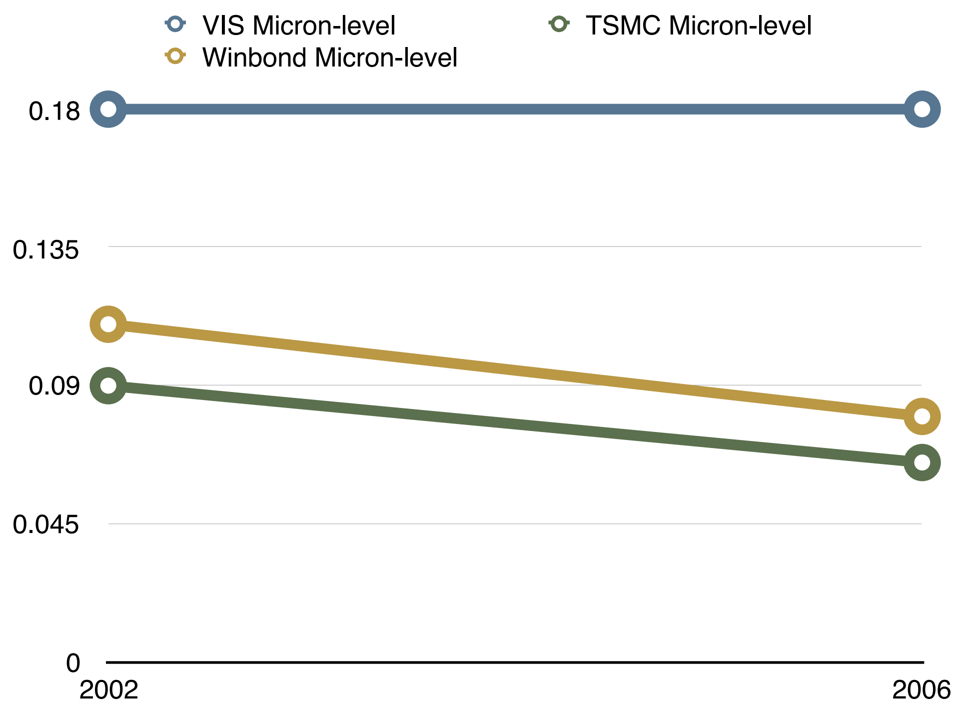
[86] Ibid., "TSMC," 2002-2005.
Ibid., "Intel," 2002-2005.
Ibid., "Texas Instruments," 2002-2005.
Ibid., "Samsung," 2002-2005.

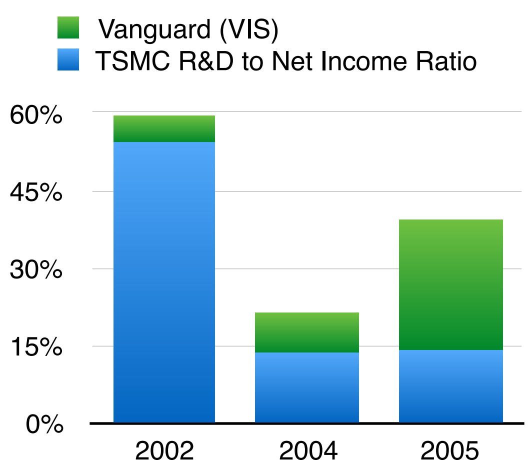
Instruments and Samsung's multiple different markets. Unfortunately, the data provided does not categorize these firms R&D into market sectors, like the pureplay-foundry.

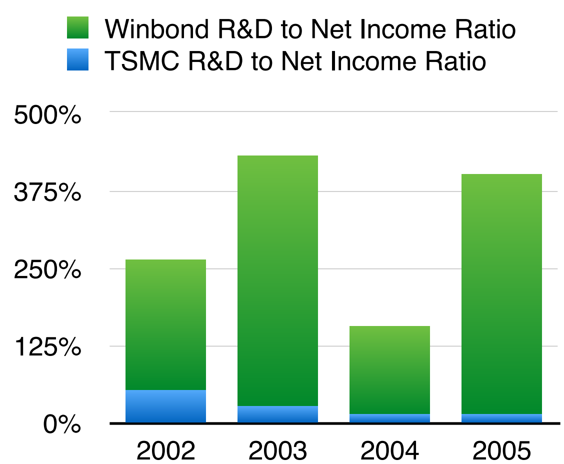
The firms Winbond, Macronix, and TSMC are respectively semi-state, private, and state origin firms that all exhibit high levels of specialization. Notably, the smaller to medium sized firms, Winbond and Macronix, consistently demonstrate higher levels of R&D to net income ratios compared to industry leader TSMC. The data ultimately suggests that late-comer firms in high-tech late-developing economies must maintain disproportionately high levels of R&D in order to specialize and find new niches within the division of labor. While this may partially be a result of State inputs and polices creating a financial system favoring the development of smaller to medium sized firms, as well as State R&D incentives and requirements within the HSIP which often matched R&D levels of the firms within the HSIP and required high levels of R&D in the first place, there may be other factors within the industry that encouraged increasing levels of specialization and continuous splits in the division of labor.

In this chapter we found that firm level decisions are impacted by a multitude of factors, and State inputs and infrastructure certainly impacts these decisions. When private capital was unwilling to make risky initial investments and R&D, public consortia like the ERSO and ITRI forged the path forward for Taiwan's domestic semiconductor industry. State policy aimed to attract and retain the technical talent of U.S.-based ethnic Chinese engineers by including them in advisory groups charged with setting the domestic industry's goals and standards. Favorable tax incentives and public infrastructure like the HSIP, which offered schools for international students, are examples of State policy not only aiming to attain the human capital of these returnees, but also the connections and resources of multinational corporations. While we've

seen how the State incorporated these returnees into State infrastructure, further analysis on the backgrounds and experiences of the leading engineers, founder, and CEOs is necessary to understand their contributions to Taiwan's domestic semiconductor industry.







Chapter 3:

Ethnic Returnee Networks and the Development of Taiwan's Semiconductor Industry

Quantifying the impact of individual returnee entrepreneurs is a difficult task as many of their influences took an institutional form through the advisory committees and public consortia they engaged and worked with. In order to truly understand the depth of their contributions, the following discussion will first analyze the educational and professional backgrounds of key policy advisors and engineers involved with Taiwan's semiconductor industry during the seeding stage to understand how their experiences helped shape key initial decisions, link Taiwan's semiconductor industry with the global industry, and facilitate early technological advancements.

This chapter will explore and analyze the incentives and motivations behind the return of ethnic Chinese talent including State tax policies and other public inputs, as well as other cultural, historical and personal motivations significant to the return of Chinese diaspora. In the final section we will turn our focus on the expansion and spreading out phase of Taiwan's semiconductor industry and explore how returnee entrepreneurs continued to lead Taiwan's semiconductor industry to achieve cutting edge technological upgrades and product specialization. Our discussion will first turn to a literary anecdote in order to provide the reader a complex understanding for reasons behind both the dispersal and return of the professional Chinese diaspora.

Abroad and Home Again: A Literary Introduction to Taiwan's Returnee Talent

The life of Saxenian's returnee entrepreneurs, specifically in the United States, is often reflected in Taiwan's literary culture. For example, "Winter Nights" by Bai Xianyong, a writer born in Guilin China at the cusp of the Second Sino-Japanese war who left mainland China for Taiwan at a young age, is relevant in our discussion of Taiwanese returnee entrepreneurs and engineers as the story is primarily a dialogue between two former classmates at Beijing University, U.C Berkeley professor Wu Zhugao, and Taiwan University professor Yu Qinlei. Through their personal narratives we can attain a deeper understanding of the historical and cultural motivations for ethnic Chinese returnees returning home, as well as leaving home, which ultimately creates bidirectional movement of Taiwanese talent between the United States and Taiwan.

The story begins with a vivid description of Yu Qinlei's home in Taiwan, serving as a metaphor for his life and current condition. "The house that Professor Yu made his shelter looked exactly the same as the other University quarters in the alley, old buildings that had survived the Japanese occupation. It bore all the scars of long neglect…moldering with decay and disrepair."[87] Later we discover that Qinlei is actually in "disrepair" as he had an accident during the May Fourth protests at Beijing University, while he and Wu Zhugao were classmates, which was further damaged by poor medical treatment at Taiwan University Hospital.[88] The narrative highlights the backwardness of Taiwan's society, specifically focusing on a lack of technological progress. Yu Qinlei views his old classmate's successful tenured life abroad at an American university with admiration and a sense of longing to have had lead a similar life abroad.[89] He also had paid for his two children to study engineering abroad at great personal financial expense. His youngest son when meeting Wu Zhu Gao took the opportunity to ask the American professor "'Is it true that the Physics Department (At U.C. Berkeley) often spends more than half a million dollars on one single experiment?' Jungian's youthful face gleamed with envy."[90] Yu Qinlei's see's both his future and his children's future abroad, expressing awe and hopefulness at the opportunity for U.S-based experience, especially in high-level scientific research. These sentiments underpinned the brain drain in Taiwan, but what Yu Qinlei does not understand is the strong feelings of those abroad like Wu Zhugao with a deep sense of yearning to return home.

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[87] Bai Xianyong, "Winter Nights," in *The Columbia Anthology of Modern Chinese Literature,* (New York: Columbia University Press, 2007), 210.

[88] Ibid., 218.

[89] Ibid., 211.

[90] Ibid., 220.

Upon Professor Wu Zhugao's long-awaited return to Taiwan, the *Central Daily News* noted that his arrival and lectures attracted the likes of more than one hundred Taiwanese scholars and dignitaries.[91] The professor is happy to give his lectures to Taiwan's academic and technocratic audiences. In fact, the next morning after his visit with Qinlei, Professor Wu planned to visit Taiwan Political University for a lecture.[92] Despite his excitement to contribute to Taiwan, and connect academica with Taiwan's technocratic class, Wu Zhugao carries a deep guilt and shame for abandoning his home and living life abroad. He specifically refers to himself as feeling like "one of Emperor Xuan Zong's white haired ladies, who just kept telling foreigners anecdotes of the Tianbao reign."[93] During the Tang dynasty Emperor Xuan Zong's court ladies are depicted in Tang funerary sculpture to represent both grace and beauty, which mirrors Wu Zhugao's extension contributions to his field.[94] However, like the older court ladies who often left home to join the court, he feels separated from his home and his only purpose to entertain the foreigners around him. Wu Zhugao feels alone while abroad, especially after his wife has passed, and plans to return to Taiwan and engage Taiwan's academic community.[95]

Bai Xianyong's story is not condemning ethnic Chinese who left for intellectual and other pursuits abroad, but instead a celebration for individuals who returned to act as conduits between their native country and highly developed countries like the United States. The story also highlights motivations behind a bi-gration, both Taiwanese professionals leaving to pursue

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[91] Bai Xianyong, "Winter Nights," 219.

[92] Ibid., 220.

[93] Ibid., 217.

[94] Kimbell Art Museum. "Chinese *Court Lady."* https://www.kimbellart.org/collection/ap-200101(accessed March 3, 2020).

[95] Bai Xianyong, "Winter Nights," 221.

further education and returning to find community and home, that focus more on cultural and historical sentiments rather than only monetary. The author's decision to have Qinlei's son study engineering was a prescient choice, especially knowing the rapid increase of engineering students as well as technological development in Taiwan that ensued during the following decades. Although the share of Taiwanese abroad students in the United States has declined since the mid 1990, the U.S continues to be the most attractive place for Taiwanese students studying abroad. Students like the Taiwanese professor's son, and the advice of academics or career professionals abroad, like Professor Wu Zhugao, would later aid in Taiwan's technological leap-frogging.

Key Returnees in Taiwan's Semiconductor Seeding Stage of Development

Many returnee entrepreneurs and engineers joined advisory committees and public consortia early in the development of Taiwan's semiconductor industry. The following discussion will analyze the educational and professional backgrounds of key policy advisors and engineers involved with Taiwan's industry during the seeding stage of the semiconductor industry to attempt to quantify how their experiences shaped key initial development decisions, link Taiwan's semiconductor industry with the global industry, and facilitate early technological advancements.

Breznitz argues that the influence of the returnee entrepreneurs only started after the returnees saw an economic opportunity in Taiwan, and not vice-versa.[96] Breznitz' view undercuts and fails to understand the importance of foreign based ethnic Chinese advisors, primarily from the United States, who helped guide Taiwan's semiconductor industry development when the industry was still in its infancy. Specifically the Technical Advisory Board (TAC) as well as the Science and Technology Advisory Group (STAG) had significant foreign based membership.[97] In 1974, Dr. Wen Yuan Pan, an RCA engineer, following an invitation from the Minister of Economic Affairs Dr. Y.S. Sun, established and led The TAC. The TAC, consisting of and led by Dr. Pan and Chinese engineers working for leading US electronics firms like IBM and Bell Labs, prepared a report to the Taiwan Cabinet on how to seed a semiconductor industry in Taiwan. The report recommended the following initiatives; Taiwan execute technology transfer agreements by inviting U.S firms to bid for a contact and specifically targeting CMOS technology, as well as offering technical training for engineers in the United States, and this activity was to be centered in a State agency.[98]

Dr. Wen Yuan Pan is known by many as the father of Tawian's Semiconductor industry and in an interview with 'medium.com' Anna Lee Saxenian notes "Pan's involvement certainly is a striking addition to our knowledge of the early ties linking Silicon Valley and regions in Asia." Born in China, Pan received his undergraduate education at Shanghai Jiaotong University and pursued a post-graduate degree in electrical engineering at Stanford University. Pan had a difficult journey as one of China's first leading electrical engineers. In fact, his Stanford

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[96] Dan Breznitz, *Innovation and the State*, 110.

[97] Hong Sul, *The Political Economy of Industrial Policy in East Asia,* 141.

[98] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 164.

education almost prematurely ended with the Japanese invasion of China in the 1930s, however he chose to stay in the United States to continue his education with hopes to return home and improve China's technological level. Pan worked at RCA for over thirty years where he was credited for securing over 30 patents.[99] While the communist victory prevented Pan's return to mainland China, he found many former colleagues from his time at Jiaotong University working in Taiwan, which— along with the fact his wife's family had strong ties to upper echelons of Taiwan's government—ultimately led him to pursue his dream of upgrading his home country in Taiwan.

Even prior to his involvement with the Technical Advisory Board, Pan had been working with his counterparts in Taiwan by regularly organizing meetings of overseas Chinese engineers. These efforts would become known as the 'Modern Engineering and Technology Seminars,' which Taiwan's returnee entrepreneurs early involvement in building connections between overseas Chinese engineers and Taiwanese technocrats. Significantly, the Chinese Institute of Engineers, established in 1917, helped coordinate these meetings and specifically focused on bringing together leading engineers with Taiwanese technocrats.[100] According to the CIE-USA website, the organization and it's Taiwanese counterparts will continue to provide technical and science seminars, as well as career development seminars and leadership seminars for continuous promotion of technological advancement and exchange in the United States and abroad. Dr. Pan's individual role in developing Taiwan's semiconductor is exhibited by a letter he sent to Dr. E. E. Terman, a Stanford professor known as the father of Silicon Valley and a mentor to Dr. Pan.

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[99] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 165.

[100] Anna Lee Saxenian, *The New Argonauts*, 136.

> I proposed a 3-phase project to develop the LSI MOS technology in Taiwan for a total Government funding of the order of ten million dollars as follows. Phase 1: 1975-1978 Technology transfer from several U.S. universities and a U.S. industrial company. Phase II: 1978-1980 Pilot production of standard circuits and several custom circuits to supply the local needs. Phase III: 1980-1985 Will gradually transfer the technology and facilities to the local industry. To my delight, the project was quickly approved, as proposed, and I now find myself deeply involved in helping the Industrial Technology Research Institute (ITRI) for implementation. We have already reached amiable agreements with the University of Florida in Gainesville and the Case-Western Reserve University in Cleveland for technical personal trainings.[101]

Dr. Pan's letter suggests his ideas had an extremely high-level of influence over the development trajectory of Taiwan's semiconductor industry. Dr. Pan's experience at RCA largely facilitated RCA's decision to share their out-dated CMOS logic processing technology with ERSO/ITRI.[102] Dr. Pan contributed greatly to Taiwan's semiconductor development prior to the industry becoming highly profitable— suggesting that although economic incentives are significant in attracting top-talent, shared history and cultural identity also represent significant motivators for the return of ethnic Chinese high-tech talent. Dr. Pan, however, may have included in his proposal for the intention of the State to gradually transfer the technology and facilities to the local industry as a means to signal to other returnee's that although high-tech developed will start in the State, the benefits of Taiwan's technological upgrading will eventually reach the private market and those poised to lead it.

Other foreign members of the TAC would later return to Taiwan to serve different roles both within State institutions like ERSO/ITRI, as well as within the Taiwan's private semiconductor industry as it developed in the late 80s and early 90s. Dr. Genda Hu, left Silicon Valley to serve as general director of ERSO/ITRI and now is the vice president of TSMC. Hu

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[101] Dr. Wen Yuan Pan to Dr. E. E. Termen, February 12, 1975.

[102] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 165.

suggests "the U.S. experience had a tremendous impact on my generation. We were exposed to world-class researchers and leading-edge technical opportunities. We observed firsthand the growth of the electronics and computer industries, and how business models and mentalities were changing."[103] These foreign returnees in advisory boards like the TAC lead and empowered others success by taking their know-how and contributing both in providing technical expertise and managerial experience as well as knowledge of industry practices and trends. These contributions guided the seeding of Taiwan's semiconductor industry. The foreign returnee contributions within the State at ITRI and ERSO helped to upgrade Taiwan's technological capabilities and provide leverage when engaging with the global market. Many of these advisory board returnees later served as leaders within the industry's private firms.

Saxenian argues that organizations like ERSO and ITRI have "limited control over the pace and direction of innovation in domestic industry. However, the public sector has played a crucial role in the governance of the industrial system."[104] She supplements her argument by pointing to key industrial policy decisions like avoiding the creation of publicly funded 'national champion' firms, as well as other important inputs like investments in higher education and research and training. While Saxenian accurately highlights the role of the State in creating a supportive ecosystem for the development of specialized producers, in some sense, her claim under appreciates the efforts of Taiwan's returnee engineers working within ITRI and ERSO during the seeding stage of industry. During this stage, ITRI upgraded the technological capacity, later dispersed to all of Taiwan, and also spun-off the two most successful pureplay-foundry

[103] Anna Lee Saxenian, *The New Argonauts*, 149.

[104] Ibid., 132.

companies in Taiwan (UMC and TSMC). Leading this charge were returnee engineers like Ding-Yuan Yang.

Ding Yuan-Yang was born in Nanjing, China, where both his parents were chemical engineers. He attended National Taiwan University, where he majored in electrical engineering. Ding Yuan Yang, like many other talented students, sought education abroad at U.S. universities. He attended Princeton University and received his Ph.D in Electrical Engineering in 1975. According to 'ithistory.org,' he worked for a brief period in the United States at Harris Semiconductor Company as a principal engineer. According to 'computerhistory.org,' Dr. Ding-Yuan Yang was a founding member of ERSO, and led the RCA-37 in their technical training overseas following the ERSO's initial technology transfer agreement. Significantly, the State actually provided for Yang's Business Administration degree at Stanford, which came in useful for Yang and the industry later when he spun-off ERSO's then outdated fabrication facility into a new company called Winbond in 1987. Without the leadership and expertise provided by returnees like Ding-Yuan Yang, the ERSO may not have had the technical expertise necessary for upgrading their outdated CMOS logic processing technology. Yang's experience with the State highlights a reciprocative positive relationship that characterized interactions between returnee engineers and the State.

Taiwan's public consortia, like the ERSO and ITRI, guided Taiwan's early semiconductor industry in terms of the setting the trajectory for semiconductor development, as well as advancing technological innovation in Taiwan. Significantly, during the seeding stage of Taiwan's semiconductor industry the State relied upon the networks and advice of key returnee engineers like Ding Yuan Yang and Dr. Pan who advised the State in organizations like the TAC

and STAG, as well as offered their technical and managerial know-how within ERSO and ITRI. These returnee engineers entered Taiwan's nascent industry prior to any sign of profitability, but they also helped structure the system to eventually reward the early leaders of Taiwan's private semiconductor industry. Our discussion will now turn to the contributions of Taiwan's returnee entrepreneurs in Taiwan's semiconductor industry following the initial seeding stage of development.

Semiconductor Start-ups and Returnee Networks: Engineers, CEOs and Capitalists

Taiwan's desire to attract top-talent is not a unique strategy for late-developing States pursuing high-tech industries. In fact, attracting top-talent is a global agenda that fosters competition between many developing high-tech economies. Recruiting high-level technical talent, or human capital, is a necessary first step to upgrading domestic tech industry and while some returnees, like Dr. Pan and Dr. Yang, were attracted to Taiwan prior to the industry becoming profitable, States cannot rely alone on shared ethnic ties and cultural identities. In the following section, we will discuss how Taiwan aggressively pursued a high-technical class of engineers by first demonstrating the potential of domestic industry with successful spinoffs UMC and TSMC, but perhaps even more important, the State began offering generous financial incentives for firms qualifying for the Taiwan Stock Exchange [105] Additionally, we will discuss how the success of UMC and TSMC largely eliminated the risk-averse attitudes of domestic venture capitalists, and facilitated the significant entry of private capital investment into Taiwan's

[105] Anna Lee Saxenian, *The New Argonauts*, 148.

semiconductor industry. The contributions of these engineers, CEOs, and capitalists helped Taiwan's new semiconductor industry develop strategies that undoubtedly increased the level of innovative activity, as well as avoid strategies that proved fallible in the returnees past experiences working in leading U.S. semiconductor firms. Ultimately, we will discuss the contributions of key returnees within the firms TSMC, Macronix, and Winbond by looking at how their backgrounds and expertise shaped their firm's development trajectory and relative success.

Taiwan's leading semiconductor fabrication firm, TSMC, is a globally competitive advanced semiconductor manufacture well connected to both the State and Taiwan's returnee entrepreneurs. Prior to the arrival of Morris Chang, Taiwan's bureaucrats recognized the need for creating advanced fabrication manufacturing facilities to prevent the outsourcing of designs and intellectual property, seen prominently by Vitelic's sale of the partially publicly funded VLSI project to Hyundai. As Clare Brown and Greg Linden note in their book *Chips and Change* "relying on vertically integrated firms for fabrication raised intellectual property concerns because of the information revealed when the design was passed to the fab, and the possibility the fab owner might decide to enter the fabless company's market."[106] Under Morris Chang's leadership ITRI recognized these problems, but also recognized the potential of developing a firm that complemented the existing industry ecosystem by focusing solely on the fabrication of chips rather than the prevalent model of large integrated device manufacturers (IDMs). [107]

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[106] Clair Brown and Greg Linden, *Chips and Change*, 54.

[107] Dong-Sung Cho and John Mathews, *Tiger Technologies,* 171.

Morris Chang, although now retired, was not the lone returnee in TSMC. In fact, sixteen of nineteen senior executives came to TSMC with American graduate degrees and work experience; additionally, although Robert Tsao CEO of UMC was not a returnee himself, in 1997, five of the top nine senior executives in the company held American graduate degrees.[108] Chang himself claims that the returnees "most important contribution is their experience in managing world-class companies like HP, Intel, and Bell Labs. They bring the disciplined management style of these businesses."[109] While in the past, Taiwanese businesses were primarily run as family businesses, bringing in the returnees with management experience in prominent U.S firms perhaps signaled to U.S firms that TSMC and others were mirroring the business standards and practices of the existing semiconductor industry. As a result, leading edge semiconductor firms were more likely to work and collaborate with the Taiwanese domestic semiconductor industry.

Technical advances also facilitated this vertical disintegration shift in the organization of production including the solidification of MOS fabrication technology as the mainstream, which "provided a predictable technology trajectory for designers to follow," as well as improvement in design transfer technology that allowed for fabless firms to seamlessly transfer their chip designs to Fabs specifically utilizing the Berkeley Transistor Simulator Model (BSIM).[110] Technical changes helped facilitate the transition to fab/fabless production models, but it was also Morris Chang's understanding of global business trends which led ITRI to pursue a pureplay foundry firm. Clare Brown and Greg Linden also note that challenges within the semiconductor industry

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[108] Anna Lee Saxenian, *The New Argonauts,* 150.

[109] Ibid., 150.

[110] Clair Brown and Greg Linden, *Chips and Change,* 46.

are often linked together, suggesting the importance of maintaining industry-wide connections and practices to better understand future development trajectories. For example, Fabrication firms, or pureplay-foundries, should pay close attentions to advances in lithography technology as "one of the central drivers of fab cost is lithography equipment, which typically accounts for 20 percent of the fixed cost of an advanced fabrication facility."[111]

While the innovative activity of the ERSO and ITRI significantly decreased following the initial spinoffs of UMC and TSMC, the legacy of these State institutions continued to support the developing private industry. "The ITRI has about a 15 per cent turn over rate annually, which implies that each year about 800 of ITRI/ERSO's staff leave to join private firms or to start their own businesses."[112] In fact, by 2000, specifically in the HSIP, a total of 4,108 returnees from overseas worked in the Science Park as well 4,464 ITRI alumni.[113] While ITRI no longer maintained its central role in terms of technology acquisition and technological development, the ITRI personal, many of whom were U.S.- based returnee engineers, were now armed with global industry connections from their time working abroad, State connections from their time working within State institutions, as well as local connections between their co-workers as many went on to found domestic firms. As a result, returnees were disproportionately likely to become entrepreneurs. Out of the 289 companies located in the HSIP in 2000, 42% of these companies founding teams were at least partially made up with returnee engineers.[114] For example, the firm

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[111] Clair Brown and Greg Linden, *Chips and Change,* 40.

[112] Hong Sul, *The Political Economy of Industrial Policy in East Asia,* 141.

[113] Anna Lee Saxenian, *The New Argonauts,* 151.

[114] Ibid., 151.

Macronix was founded by returnee engineer and CEO Miin Wu, who also recruited over 40 U.S-based ethnic Chinese engineers for the launching of his successful company.[115]

Following the founding of TSMC and the falling back of ERSO and ITRI's role in guiding the semiconductor industry, the number of Taiwan's IT industry 'organizational events' dramatically increased. From 1976 to 1985 Jou Sue-Ching and Chen Dung-Shen's study found that there were 11 total events facilitating organizational connections among Taiwan's local producers as well as among Taiwan's domestic IT industry and primarily U.S- based firms. In the following 10 years, 1985-1995, the same study found there were 348 'organizational events' creating domestic and global IT industry networks.[116] While the data collected was based on all IT industry activity in Taiwan, we contend that the magnitude of difference between Taiwan's semiconductor industry and Taiwan's IT industry is minimal. Additionally, from 1985 to 1995, the number of returning entrepreneurs in Taiwan skyrocketed.[117] Ultimately, the data suggests that while the State's public consortia played an important initial role in developing industry connections both within and outside of Taiwan, when the rate of ethnic Chinese U.S- based engineers entering Taiwan's semiconductor dramatically increased, so did cross-regional Taiwanese semiconductor industry connections.

Macronix, founded in 1988, is an excellent case study for examining the impact of returnee engineers, CEOs and venture capitalists as the firm was one of Taiwan's first semiconductor firms completely funded by venture capital and the first semiconductor firm to be

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[115] Dong-Sung Cho and John Mathews,"*Tiger Technologies,* 176.

[116] Jou, Sue-Ching, and Dung-Sheng Chen. "Keeping the High-tech Region Open and Dynamic: The Organizational Networks of Taiwan's Integrated Circuit Industry." GeoJournal 53, no. 1 (2001): 83.

[117] Anna Lee Saxenian, *The New Argonauts*, 149.

listed on the Taiwanese Stock Exchange. Founder and CEO Miin Wu received his Master's degree in Material Science and Engineering from Stanford University. According to Macronix's corporate website, prior to establishing Macronix, he held senior and managerial positions with VLSI Technology Inc, Intel Corp, Rockwell International and Silixonix Inc. in Silicon Valley. As the first semiconductor firm listed on Taiwan's Stock Exchange, Macronix benefited immensely from the attractive regulations surrounding employee-stock options. Taiwan's taxes on employee stocks were on the basis of its price when issued rather than the current market value; Taiwan eliminated its capital gains taxes in 1990, therefore no taxes were collected when shares were sold and returnee engineers who brought capital gains from other jurisdictions were not taxed on those gains either.[118] As a result of these favorable conditions, by the mid 1990s, Taiwan's salaries for senior managers were three of four times higher than their equivalent U.S. peers.[119] The State's tax structure gave tax breaks specifically aimed to facilitate companies offering very attractive employment offers to top foreign engineers. Under Wu's leadership Macronix became a leading world-class producer of flash-memory chips.[120] Significantly, this development was facilitated by Macronix's partnership with the US- based MNC VLSI Technology Inc, which Wu had worked for and developed personal and professional relationships.[121]

While Macronix was one of Taiwan's first non State or even semi-State firms, the structure of Taiwan's system did not attempt to stop the development of competitors to the State firms. Macronix's technical and managerial guidance from the predominantly U.S- based ethnic

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[118] Anna Lee Saxenian, *The New Argonauts,*148.

[119] Ibid., 151.

[120] Dong-Sung Cho and John Mathews, *Tiger Technologies,* 176.

[121] Ibid., 175-176.

Chinese engineer workforce and leadership helped to achieve the firms' aims to serve a customer base primarily in the United States, Japan and Europe by quickly recommending the development of a "targeted a range of niche products needed by next-generation PC's and communication products."[122] The choice to focus on a highly specialized niche can be credited partially to the foreign returnees understanding of industry trends and practices. Additionally, as discussed in the previous chapter, State incentives greatly encouraged intensive R&D investments, especially within the HSIP where Macronix located their first VLSI facility. Owing to the high level of specialization, TSMC and UMC must not have viewed Macronix as a threat to their business. In fact, TSMC helped the young company remain profitable and efficient by buying unused fab space and capital equipment that was largely unrelated to Macronix's specialized products and also helpful for TSMC's goal to achieve massive economies of scale.[123] Hence Taiwan's semiconductor industry developed so that new firms often specialized and complemented the activities of other Taiwanese semiconductor industry firms. These local industry connections proved to be extremely valuable tools for maintaining relevance and cohesion within the industry.

Perhaps the most significant contribution of these returnee entrepreneurs was their ability to recognize and understand the dynamics of industry trends and then push the State or private companies to create a development plan that is forward looking and maximizes returns. As discussed previously, Dr. Ding Yuan Yang's work at ERSO greatly impacted the success of Taiwan's seeding stage of semiconductor development. Dr. Yang's contributions to Taiwan's

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[122] Dong-Sung Cho and John Mathews, *Tiger Technologies,* 176.

[123] Integrated Circuit Engineering, "Macronix International," 1994.

semiconductor development continued through his founding of Winbond Electronics and the strategical guidance he provided. Dr. Yang's knowledge of the global semiconductor industry, specifically the trend of vertical disintegration and outsourcing of production, poised his firm Winbond for success.

Dr. Yang in 2004 wrote an article for a semiconductor manufacturing technology workshop. The article highlights his in-depth understanding of global business trends and the opportunities these trends gave to those who recognized them. Dr. Yang understands that outsourcing in the semiconductor industry is triggered by "the threshold in developing highly complex SoC products and the solutions escalates quickly…very few companies are self-sufficient in IP and in doing SoC from scratch and within own company…many companies like to focus on their own competence."[124] Dr. Yang knew that many global IC design firms were looking for a reliable partner to outsource the fabrication of their chips. He also knew in order to become a reliable partner and solve complex problems, his firms technological level must continuously advance. As a result, Winbond moved quickly to upgrade existing fab capabilities and built a second fab in 1992 which "incorporated the most advanced submicron technology, taking Winbond to a prime position in the Taiwan industry."[125] Winbond moved ahead with ambitious fab expansion plans even despite operating for a time at a negative cash-flow.[126] Both Winbond's high-levels of R&D to net income ratios, as well as continuous fab expansion and technological upgrading aimed to create a fabrication firm that allowed fabless firms, primarily

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[124] Ding-Yuan Yang, "The outsourcing of SoC product development: Taiwan as the global center for SoC implementation," *2004 Semiconductor Manufacturing Technology Workshop Proceedings* (IEEE Cat. No.04EX846), Hsinchu, (2004): 1.

[125] Dong-Sung Cho and John Mathews, *Tiger Technologies*, 175.

[126] Ibid., 175.

from the United States, to focus on their own objectives and hand off the product with confidence in the manufacture's technological competencies. Winbond's willingness and ability to spend large amounts of capital quickly, as well as Winbond's ranks of engineers with foreign experience in the global IT industry assured foreign producers Winbond would continue to upgrade fab technologies at the same level as the global cutting edge. Additionally, Winbond's expansion of fab capabilities assured IC design suppliers that their product would have a quick time to market, as well as provided evidence for incumbent firms like Toshiba that a tech-development deal with Winbond could foster innovation in both for both Toshiba and Winbond. As a result, Winbond developed both in-house capabilities for technology innovation, as well as tapped into the innovative and advanced resources of the existing incumbent semiconductor firms.[127]

TSMC, Macronix, and Winbond are all successful semiconductor manufacture's with technological capabilities close to or at the global cutting edge. Significantly, both TSMC and Winbond benefited directly from the ERSO and ITRI semiconductor projects. The tech transfers from the State allowed these firms to enter the market with already sophisticated technologies, which provided Taiwan's firms the leverage needed to form cross-licensing agreements, technology development partnerships and tech transfers from foreign MNC's like Phillips, Toshiba, and Intel. As Saxenian argues "unlike Japan in the 1980s, Taiwan followed imitation with differentiation, not with direct competition."[128] Taiwan's semiconductor industry never aimed to supplant the existing high-tech infrastructure in the United States, specifically in Silicon

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[127] Integrated Circuit Engineering, "Winbond Electronics," 1999.

[128] Anna Lee Saxenian, "Taiwan as Partner and Parent," in *The New Argonauts: Regional Advantage in a Global Economy,* (Cambridge: Harvard University Press, 2007), 163.

Valley. In fact, firms like Winbond often collaborated with Taiwanese engineers like Fred Cheng, who "had worked in Silicon Valley for twenty years but knew Taiwan's technology community as well because he traveled to headquarters at least ten times a year."[129] Taiwan's silicon valley engineers traveled home far more consistently than their Indian and mainland Chinese counterparts; "only 36 percent of the Taiwanese hadn't visited Taiwan in the past three years," significantly lower than mainland Chinese 56 percent and 48 percent of Indian engineers."[130]

Conclusion

Taiwan's returnee entrepreneurs contributed to the development of Taiwan's semiconductor industry in a multifaceted manner. During the seeding of Taiwan's industry, returnee engineers like Dr. Wen Yuan Pan, Dr. Ding Yuan Yang and others helped shape the direction of development from within State institutions like the ERSO, ITRI, TAC, and STAG. These organizations maintained a large foreign membership with experience in large incumbent technology firms, like Texas Instruments, Intel and Bell Labs. The returnees informed and advised the decisions of these organizations, which as discussed in Chapter 2, Taiwan's semiconductor industry would not have succeeded without. The technical experience, personal and private networks as well as managerial experience of Taiwan's returnee population continued to lead both the large State-origin firms like UMC and TSMC as well as Taiwan's private semiconductor firms like Winbond and Macronix. Winbond's and Macronix's high levels of

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[129] Anna Lee Saxenian, *The New Argonauts,* 163.

[130] Shenglin Chang, *The Global Silicon Valley Home: Lives and Landscapes within Taiwanese American Trans-Pacific Culture* (Stanford: Stanford University Press, 2006), 41.

specialization are both a reflection of State policies that encouraged and subsidized R&D funding, as well as a reflection of returnee entrepreneurs' knowledge of global business trends, like outsourcing and the disintegration of vertical production, which rewarded Taiwan's firms with high technological levels and specialized products.

Chapter 4:

Findings from Taiwan's Semiconductor Industry and Potential Future Implications

Taiwan's semiconductor industry, specifically the pureplay-foundry, has achieved a high level of success both in terms of global market share and technological capabilities. There are multiple actors in Taiwan that deserve credit for the industry's remarkable success. The State, primarily through public research consortia, advisory groups, and favorable tax and financial incentives, helped to guide the industry in infancy, as well as facilitate the attraction of top technical talent to Taiwan. Ethnic Chinese returnee entrepreneurs and their personal and professional networks helped form the recommendations of groups like the TAC and STAG, which ultimately informed and shaped the decisions of Taiwan's technocrats during the seeding stage of Taiwan's semiconductor development. Additionally, the returnee engineers and

entrepreneurs continued to aid the development of Taiwan's industry as more and more small to medium sized private firms emerged in the 1990s and early 2000s. Without the State's tailoring of policy to attract returnee entrepreneurs, and without the returnee's technical talent, managerial know-how and work experience it is unlikely Taiwan would have achieved the current level of semiconductor success.

The structure of Taiwan's financial system, which reduced patient capital and had historically encouraged the development of small to medium sized businesses, as well as early State decisions—like choosing not to develop the project which would eventually become TSMC within UMC—resulted in less concentration of industry power and revenue within Taiwan's top firms. The industry benefited and increased innovation owing to the competitive nature of having many firms, both large and small, with high-technological capabilities. Each firm had to find a specialized niche within different semiconductor fabrication types and conduct high levels of R&D. Oftentimes larger firms like TSMC would facilitate smaller to medium sized firms specialization as TSMC would buy unused fab space and technology no longer relevant to the smaller firm, but helpful for a large firm like TSMC for maintaining economies to scale.

The State utilized a wide range of public instruments to attract the technical talent of Taiwanese-American U.S based engineers and entrepreneurs. The National Science Council's Hsinchu Science Based Park provided both the industry infrastructure for physical production, provided educational infrastructure for the english-speaking children of returnee engineers, and located the high-tech industry in close proximity to Taiwan's top engineering universities. The park facilitated the development of both cross-regional as well as domestic networks of producers. The HSIP as well as early State efforts initiating cross-regional collaboration, such as

the METS seminars, aided the development of Taiwan's semiconductor industry. Additionally, the State's inclusion of local technical and engineering schools in product R&D allowed different levels of Taiwanese society to work together to achieve a common goal, technological expansion.

While the State may have been the locus of technological innovation during the seeding stage of Taiwan's semiconductor industry, key returnees like Dr. Wen Yuan Pan and Dr. Ding Yuan Yang helped create the State's infrastructure, and then led the infrastructure—public research consortia— responsible for advancing Taiwan's micron technology. Dr. Yang led ERSO during the upgrading of the transferred RCA micron technology from 7 micron to 1 micron technology. The connections of the returnees facilitated Taiwan's initial tech transfers— such as Dr. Pan's connections to RCA where he preciously had worked—helping ERSO and Taiwan with their first steps towards creating their own semiconductor manufacturing technology.

Following the spinoffs of UMC and TSMC, ethnic Chinese U.S- based engineers began returning to Taiwan in large numbers to join one of Taiwan's new promising semiconductor firms or found their own. Taiwan's market was notably more attractive than other similar East Asian late developers as new small and medium sized firms were common in Taiwan. As a result, founding a new semiconductor or high-tech firm in Taiwan had significantly lower barriers for entry than States like Japan and Korea where the majority of IC and high-tech activity occurred within a few massive conglomerates. Additionally, generous financial tax loop-holes and subsidizes allowed Taiwan's semiconductor firms to offer attractive compensation packages, which often included equity in the company for top-management positions. While these incentives successfully attracted top foreign talent to Taiwan, one may question how necessary these incentives were. Bai Xianyong's short story "Winter Nights" suggest that many returnees

may have returned to Taiwan in order to give back to their home country and re-establish close connections with former classmates from childhood and early adulthood. Dr. Pan and Dr. Yang both returned to aid Taiwan's infant industry without any guarantee for significant returns. While not directly attributable to the State's generous tax loopholes for the top returnee technical talent, during the period of semiconductor development in Taiwan according to the website statistics (1980-2018), the Gini coefficient, a measurement of societal inequality, increased from below 30 in the 1980s to 33.8 as of 2018. Despite Taiwan's technological upgrade and significant economic growth, Taiwan's society is no exception to rising global inequality. Further research on the relationship between State sponsored tax loopholes and subsides and societal inequality measurements must be done in order evaluate whether or not the two are directly related.

Almost a majority of Taiwan's semiconductor industry leadership is at least in part made up by foreign returnees. Leaders like Miin Wu, Morris Chang, and Dr. Ding Yuan Yang armed with knowledge of industry trends, technical know-how and managerial experience helped guide their firms to achieving high levels of specialization in an innovative yet complementary role to the existing semiconductor industry, primarily in the United States. Without the contributions of these foreign returnees, finding a niche in the global division of labor might have proven too challenging for domestic producers without an in-depth knowledge of the existing industry practices and patterns.

A Rising Competitor: China's Push for Semiconductor Dominance

In 2015, China launched an ambitious technological advancement initiative called 'Made In China 2025.' A large part of this initiative is China's attempt to create an entire semiconductor supply chain—from design to fabrication to testing and assembly—within China's borders.[131] As summarized above, there are many lessons and policies China could borrow from Taiwan's successful high-tech late-developer model; however, Taiwan's industry never aimed to become a direct competitor to the incumbent IC firm's in the United States. Additionally, Taiwan's entrepreneurs, engineers and capitalists have already played a significant role in bringing talent, venture capital and foreign direct investment to China. Many of the same Ethnic Chinese technology associations which helped facilitate cross-regional connections in Taiwan, like the Chinese Institute of Engineers and the Chinese American Semiconductor Professional Association (CASPA), maintain similar services for mainland Chinese engineers.[132]

China has established multiple high-tech parks similar to the style of Taiwan's Hsinchu Science Based Park. For example, the Zhangjiang High-Tech Park in Shanghai is China's largest park with significant investments from foreign enterprises. As of 2011, the Park attracted significant FDI investments, but was not as successful at achieving significant tech-transfers to Chinese domestic firms as Taiwan.[133] There were vast technological gaps between the foreign and domestic firms within the Park, and as seen in Taiwan, firms with dramatically lower

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[131] Bjorn Conrad and Jacqueline Ives, "Made in China 2025." *Mercator Institute for China Studies* (2016).

[132] Leng Tse-Keng, "Economic Globalization and It Talent Flows Across the Taiwan Strait: The Taipei/Shanghai/Silicon Valley Triangle," *Asian Survey* (2002): 248.

[133] Gang Zeng, "The Role of High-Tech Parks in China's Regional Economy: Empirical Evidence From the IC Industry in the Zhangjiang High-Tech Park, Shanghai," *Erdkunde* (2011): 50.

technology capabilities are less likely to receive tech transfers and patent cross-license agreements.

The difference in geopolitical circumstances between China and Taiwan at the times they pursued tech transfers from abroad are significantly different. Taiwan, as an island nation of only 24 million, never represented a significant challenger to America's global technological, political, and economic hegemony. Perhaps, as a result of Taiwan's relatively weak geopolitical status and lack of capital, Taiwan's industry was forced to seek out a complementary role within the global semiconductor division of labor rather than pursue the highest value-added segments of the semiconductor supply chain. American firms making deals with Taiwanese firms in the 90s and early 2000s shifted part of the United State's high-tech economy, but at the time outsourcing was a business norm that did not raise questions relating to political issues, like national security. On the other hand, China is a nation that is increasingly recognized as global economic leader and a challenger to U.S geopolitical and economic authority. China has large quantities of capital resources to challenge any incumbent high-value added and capital intensive industry. For example, China's National Integrated Circuit Fund recently raised over $29 billion dollars from different State sources. As a result, a comparison to Taiwan is limited in that the two operate under different economic conditions and the capital constraints that held back Taiwan do not exist for China. Further comparative analysis between Taiwan and China's semiconductor development models may yield conclusions on the likelihood of China achieving the technological cutting edge in semiconductors and creating an entire industry ecosystem within one country.

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