Taiwan: Semiconductor Cluster

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Course Paper

May 2, 2007

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1. Introduction

Taiwan, situated in the East China Sea, is approximately equal to the size of Belgium (36,000 square km) and has a population of 23 million. It is one of the ten most densely populated countries in the world. With a GDP per capita of $31,390 in 2006, Taiwan is relatively wealthy.[1] Despite its ambiguous nationhood status, which precludes Taiwan's membership in important international organizations such as the United Nations, Taiwan is a full member of the World Trade Organization and is a significant player in the global market. Taiwan's average annual GDP growth of 7% since World War II has catapulted it into global prominence. Even in the 1980s and 1990s, when global economic growth slowed somewhat, Taiwan's economy still grew at a rate of 5.3% per year[2]. This growth was largely due to the rapid development of its electronics industry, most importantly its semiconductor segment. This report will examine the Taiwan economy as a whole and the semiconductor industry in particular. This paper discusses the key elements of Taiwan's "growth miracle" and how the country developed a world-class semiconductor sector. Our analysis also brings to light key issues facing the country and cluster and offers recommendations going forward.

2. Country Analysis

2.1. Position, Brief History and Political Tension with Mainland China

Taiwan is an island, strategically positioned close to several major Asian economic countries, including Mainland China, Japan and countries in South East Asia. The island is about 120 km off the southeastern coast of mainland China, located across the Taiwan Strait. With the defeat of the Chinese Qing Dynasty's during the First Sino-Japanese War in 1894–95, Taiwan was occupied and colonized by the Japanese. This colonization was endured until the end of the Second World War. In 1949, after three years of the Chinese Civil War, the Kuomintang (KMT) was defeated by the Communist Party of China and retreated to Taiwan from Mainland China. The KMT and Taiwan's succeeding political parties as well as Mainland China's leadership have continued to spar to claim sovereignty of Taiwan, a main source of the half-century long political tension between Taiwan and Mainland China.

[1] Economic Intelligence Unit, Taiwan Country Data
[2] CIA World Fact Book (2007) and Taiwan Department of Investment Service

The political tension was greatly shaped by the stance of the United States and the comparative economic strength of Taiwan versus Mainland China's. Before 1971, Taiwan was the only representative of China in United Nations but was replaced by China at the end of that year. In the early 1970s, due to Cold War politics, the U.S. approached Mainland China in an attempt to normalize relationships. As a result, the "Joint U.S. - China Communiqué, Shanghai" was signed and the U.S. for the first time after 1949 stated "there is but one China and that Taiwan is a part of China"[3]. This change greatly shaped the political stance of Mainland China and its relationship with Taiwan. At that time, Mainland China was still heavily engaged in the Cultural Revolution, and did not pay much attention to economic development. While Taiwan lost its seat in the UN, it maintained influence because of its steady and high economic growth and close relationship with the United States. Taiwan's politically weak but economically strong position has changed somewhat since Mainland China implemented its economic reform in 1978, launching a period of unprecedented growth. As Mainland China has become one of Taiwan's most important trading partners, the two nations have taken on a complicated, partly-symbiotic, partly-hostile relationship.

We have identified the political tension between Taiwan and Mainland China as a key issue to be addressed. Recommendations for this issue are presented in the final section (Issue #1).

2.2. Taiwan's Country Balance Sheet in 1950

In terms of its economic history, Taiwan has a long tradition of being an open economy and an exporter to the rest of the world. This legacy has been important in shaping Taiwan's policy towards trade, including the relative ease with which it abandoned import substitution (discussed in detail later). During World War II, Taiwan served as a production site for the Japan army, manufacturing heavy equipment. As Japan withdrew from the island, it left behind not only significant hard assets, but also good quality infrastructure – including roads and ports – as well as a highly developed primary and secondary education system[4].

As the KMT retreated to Taiwan, they allegedly brought a large amount of gold and foreign currency reserves. This capital influx, together with the human capital influx of two million Mainland Chinese, mostly intellectuals and skilled workers, put the island on a very good starting point for growth. The political relationship with the United States government was also an asset, helping Taiwan defend its independence against the Communist government in China.[5]

[3] See detail of the agreement at: http://www.ait.org.tw/docs/keydocs/shanghai_e.pdf
[4] Hsiao, F. and Hsiao, M (2002) and Scott, Bruce R. (2005).
[5] Ranis, G. (2002) "Lessons from Taiwan's Performance: Neither Miracle nor Crisis"

Despite these assets, Taiwan in 1950 had a number of serious liabilities. Political instability was rife; though this was subsequently solved as the KMT consolidated power and exercised dictatorial power over the nation. Taiwan's had few natural resources such as coal and oil, to support its manufacturing economy. However, what resources Taiwan once had were quickly exhausted. For example, during the Japanese occupation, forestry resources, particularly firs, were heavily harvested for the construction of shrines.[6] Also, arable land was scarce, forcing Taiwan to take significant steps to modernize its agricultural sector to feed its population.[7] Taiwan frequently experienced natural disasters including earthquakes and typhoons, which significantly increased local construction and transaction costs.[8]

2.3. Economy from 1950 to present

The island's economic progress was characterized by three main periods of growth. From 1949 to 1962 the country rebuilt itself under strong government control. Previous Japanese firms were nationalized (and later re-privatized). The focus was on commodity production and import substitution. From 1962 to 1982, realizing that import substitution would not work in the long run, the government quickly moved toward export promoting policies and built upon Taiwan's prior tradition as an exporting economy. Many Export Processing Zones (EPZs) were established during this period. Since 1982, Taiwan's economy has been characterized by aggressive export promotion in high-tech areas. Several factors, including rising wages and limited technology transfer, eventually led to the decline in the usefulness of EPZs[9]. Nonetheless the economy continued to flourish under the domination of successful local firms as the government shifted its focus from EPZs to Science Parks. The strategic shift from EPZs to Science Parks enabled Taiwan to experience broad-based technological diffusion with increased viability of various industries.[10]

[6] Hsu, M. J. and Agoramoorthy, G. (1997). "Wildlife Conservation in Taiwan"
[7] Ranis, G. (2002) "Lessons from Taiwan's Performance: Neither Miracle nor Crisis"
[8] Ding, Y., Chan, P.C., Fang, H.Y. (2003) "Environmental Geotechnical Problems in the Taiwan Strait Area"
[9] Fitting, G. (1982), "Export Processing Zones in Taiwan and the People's Republic of China"
[10] Li, K.T. (1998) "The Evolution of Policy Behind Taiwan's Development Success"

2.4. Current Economic Position

Taiwan's economy has grown rapidly over the past five decades. Through a combination of sound economic policy and an export-oriented strategy, Taiwan's GDP growth rate has been one of the highest in the world. From 1966-2005, Taiwan's annual nominal GDP growth rate averaged 7.7% with exceptionally high growth in late 1960s and early 1970s.[11] Taiwan's real GDP per capita is relatively high compared to those of other countries in the region.

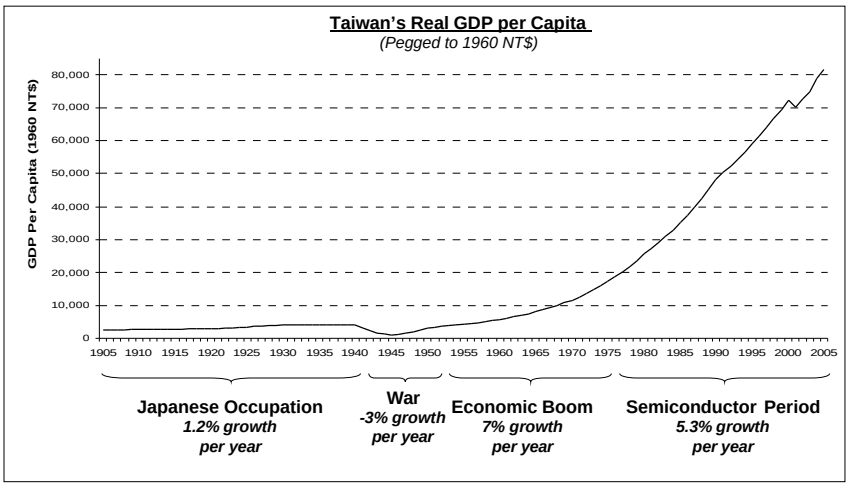


Table 1 - Source: Taiwan of Department of Investment Services, Professor Tsong-Min Wu (National Taiwan University)

Ever since 1981, Taiwan has been a net exporter of goods and services. The trade surplus has recovered steadily after the Asian financial crisis and reached a record level of US$22 billion in 2003[12]. However, the trade surplus growth has been volatile, particularly after the fast growing period of the 1980s and early 2000s. The trade surplus growth rate has ranged from 200% to -50% over the past years. This high volatility reflects Taiwan's over-reliance on a few export markets. Taiwan must address this exports concentration issue and its policy implications.

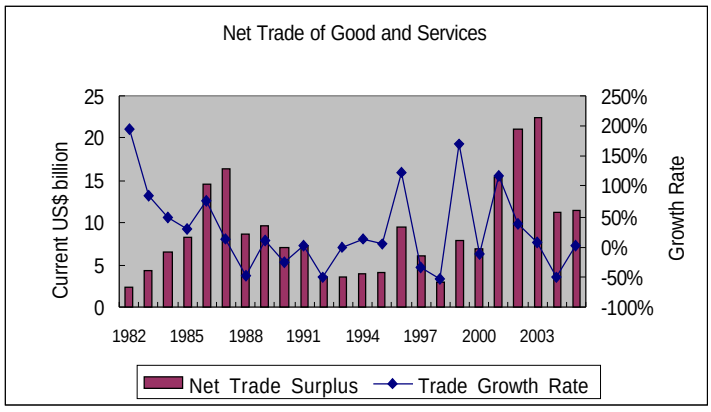


Table 2 – Source: World Development Indicators

[11] WDI, Harvard University; Taiwan Dept of Investment Services, Professor Tsong-Min Wu (National Taiwan University)
[12] Directorate General of Budget, Accounting and Statistics, "Statistical Yearbook of the Republic of China 2005" (October 2006)

High trade surpluses have made Taiwan the third largest holder of foreign reserves, after Mainland China and Japan. These hard currency reserves helped Taiwan stand firm during the Asian financial crisis in 1997 because speculators were unable to attack a country with such deep reserves and a healthy balance of trade.[13] In terms of its exports, Taiwan has a well-diversified export portfolio with many of its industries gaining high world export share. Taiwan is the world's largest supplier of computer monitors and is a leading PC manufacturer. [14] Electrical and electronics products make up the largest share of Taiwan's export portfolio. Taiwan has a number of sizeable industries other than electronics that have been capturing global trade share, including positions in minerals and oils, organic chemicals, and optical and medical products.[15]

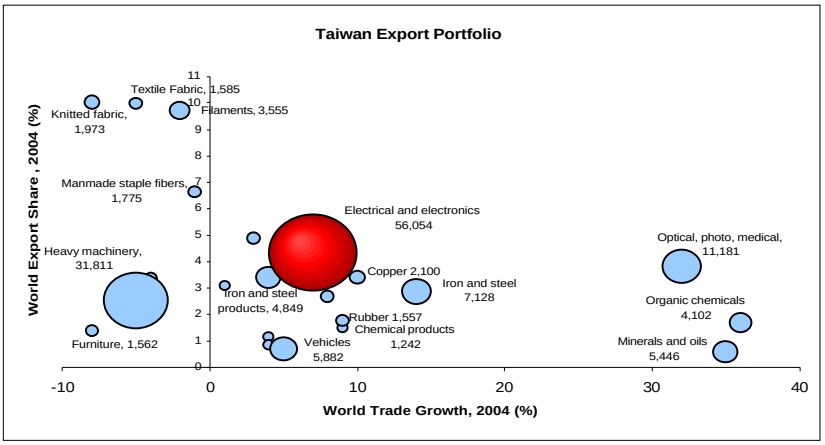


Table 3 – Source: WTO

Taiwan's trade is highly concentrated among a few key countries. The United States is Taiwan's largest trading partner both in terms of total exports as well as electronics exports. Mainland China and Hong Kong are Taiwan's two other largest trading partners, each accounting for 18% of Taiwan's exports. Japan accounts for 9% of Taiwan's overall exports and 10% of the country's electronics exports. Taken together, Taiwan's top four trading partners – the U.S., Mainland China, Hong Kong, and Japan – account for 65% of total exports.

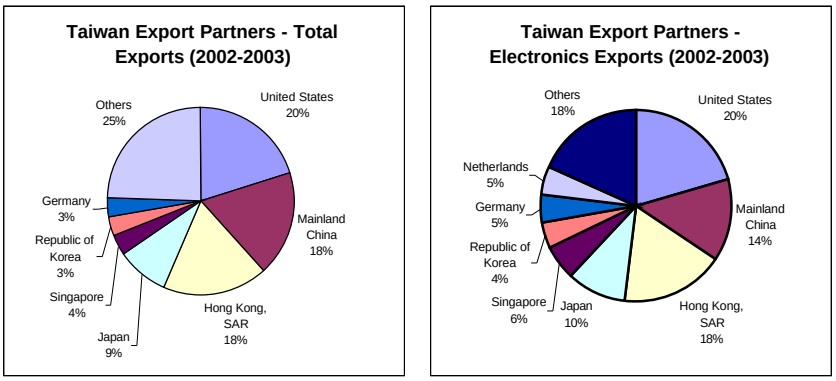


Table 4 - Source: WTO

[13] Hsiao, F. and Hsiao, M (2002) "Taiwan in the Global Economy: Past, Present, and Future"
[14] CIA World Factbook
[15] World Trade Organization

While having concentrated export markets has served Taiwan well over the past decades, there is reason to believe that export diversification is in order. China now accounts for such a sizeable portion of Taiwan's trade that this may further engender political tensions. Secondly, if the Chinese economy were to suffer, the knock-on effects on Taiwan would be profound.

We have identified Taiwan's export concentration as a potential problem to be remedied. Recommendations for this issue are presented in the final section (Issue #2).

One interesting aspect of Taiwan's growth is the degree to which it has been fueled by local savings and not foreign direct investment (FDI). As per the chart below, FDI inflows have only recently reached the 1-2% of GDP level. During Taiwan's formative years, from the 1950s-1980s, FDI played a minimal role in its growth. Considerable technological diffusion occurred from Western firms, but actual business investment was driven locally.

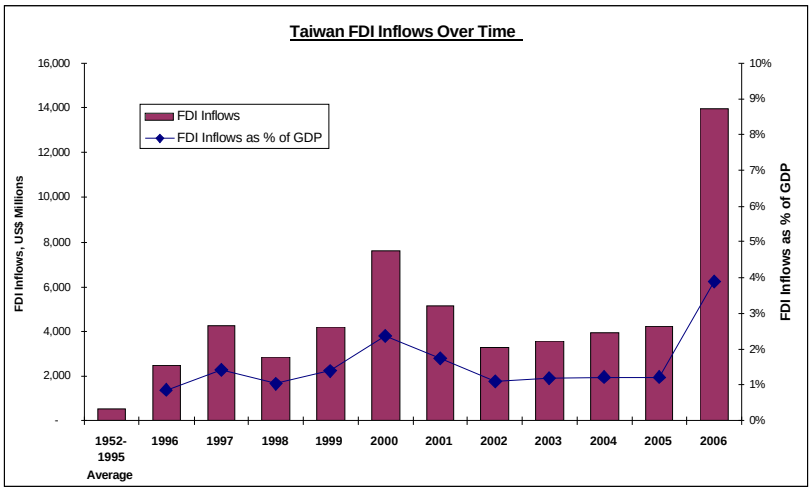


Table 5 - Source: Taiwan Department of Investment Services.

2.5. Productivity and Competitiveness

Taiwan's productivity has been extraordinarily high over the past 25 years. Labor productivity has grown by 4-5% a year; and total factor productivity has grown by an annual average of approximately 3%. The figures below show both annual productivity growth measures and the cumulative effect of such growth. For example, industrial production has more than tripled since the late 1970s. Much of this productivity came from government reforms in rural and industry development as well as consistent pro-business policies.

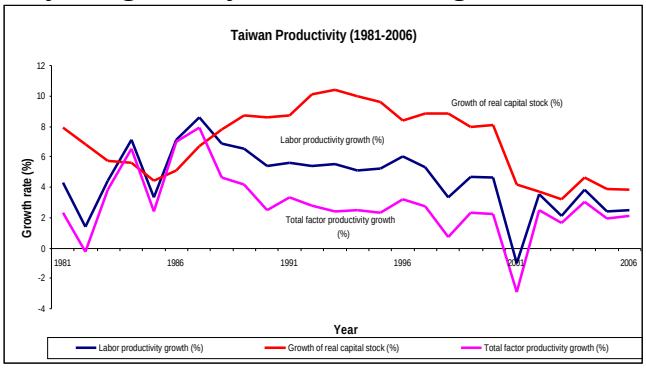
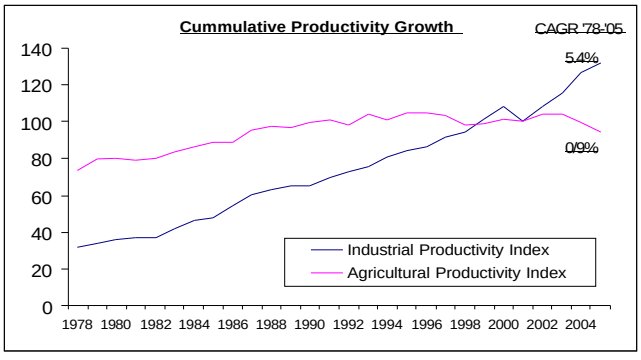


Table 6 – Source: Economist Intelligence Unit



Note: Graph scaled to 100 in 2001
Table 7 - Source: Taiwan Ministry of Economic Affairs.

Taiwan is also strong in patent registration. It has about the same patent growth rate as its neighboring countries, namely South Korea and Hong Kong. However, Taiwan is particular strong in its patents penetration ratio which is measured by the number of patents per million residents. In terms of this ratio, Taiwan ranks among the world's top countries along with U.S. and Japan, with around 280 patents registered in U.S. per million residents in the year 2005. This high ratio also reflects Taiwan's move toward a knowledge-based economy with high level of innovation.

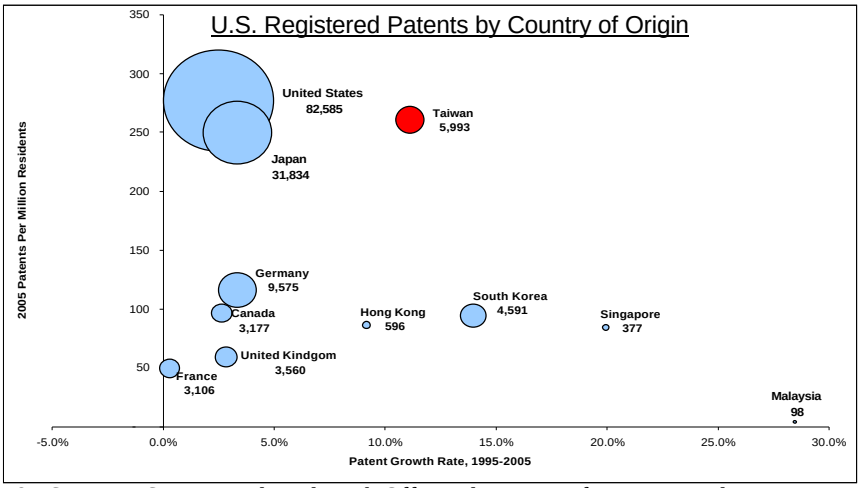


Table 8 - Source: US Patent and Trademark Office, Electronic Information Products Division, Patent Technology Monitoring Branch (PTMB)

2.6. Business and Political Environment

Taiwan's business environment is leagues ahead of Mainland China's. However, if we compare Taiwan to other Asian nations – Singapore, South Korea, Hong Kong, Malaysia – the relative position of Taiwan is mixed. In key measures (as shown in the comparative chart below),

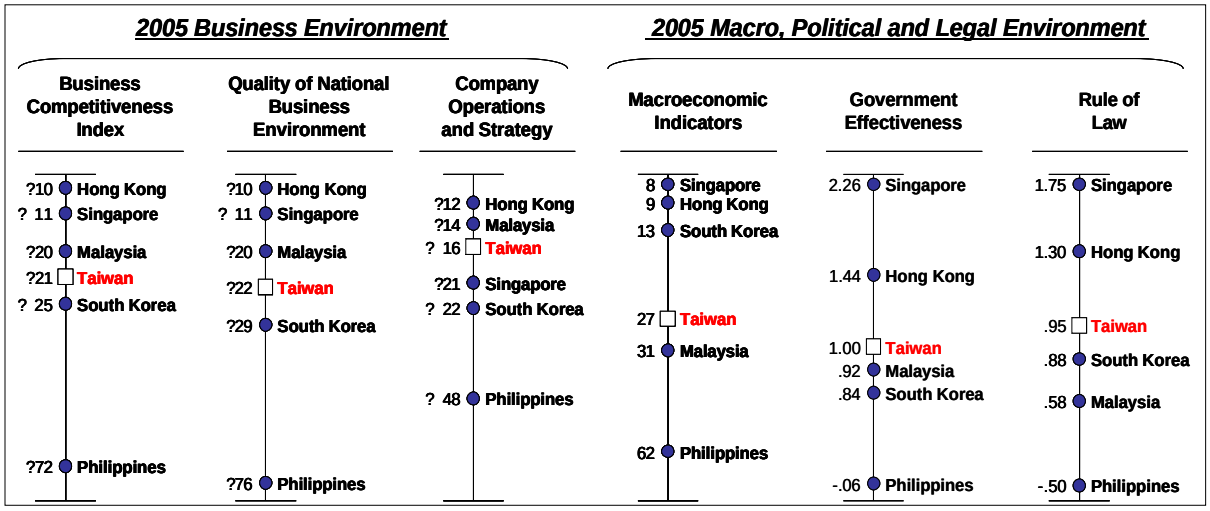


Table 9 - Source: Global Competitiveness Report 2006-2007 (World Economic Forum), Economist Intelligence Unit. – Taiwan Country Report, World Bank.

Taiwan consistently scores below Singapore and Hong Kong, and in certain areas falls behind Malaysia. Despite Taiwan's current rank of 20 among a peer group of 100-plus countries covered by the Global Competitiveness Report, its falling business competitiveness and quality of national business environment indexes raise concerns about the nation's future competitiveness.

The following table shows Taiwan's ranking in some key areas in 2006:

Government procurement of advanced technology	3	
Prevalence of foreign technology licensing	5	STRENGTH
University / industry research collaboration	7	
Local equity market access	8	
Judicial independence	39	
Business cost of corruption	35	WEAKNESS
Financial market sophistication	33	

Table 10 - Source: compiled from data given in Porter (1998): Building the Microeconomics Foundations of Prosperity: Findings from the Business Competitiveness Index

From the table, we can see that Taiwan is doing well in areas of research, technology and local financing, yet it must improve the sophistication of its financial market and the effectiveness of its judicial system to remain competitive and productive. A significant obstacle facing Taiwan's economy and its newly emerged democratic system is corruption. In recent years, Taiwan's politics has been rigged by high-profile corruption investigations, involving even the President's family members and some presidential candidates. Correspondingly, the business cost of corruption in Taiwan is also high, making it less attractive to foreign investors.

We have identified increased corruption and Taiwan's weak judiciary as key institutional issues to be addressed. Recommendations for this issue are presented in the final section (Issue #3).

In terms of Taiwan's political environment, for four decades Taiwan's government was dominated by the Kuomintang, which deserves credit for steering the economy in the right direction at key junctures. The democratization process only started in the last decade, putting the country's political environment into more turmoil than it has experienced in its fast development phase. Despite the numerous advantages of democracy in Taiwan, bi-partisan politics sometimes creates roadblocks in decision-making on key strategic issues such as macroeconomic policy and budget deficits. In the past, Taiwan has been held together by its adversarial relationship with Mainland China and the urge of national unity to fight against potential Chinese invasion. Yet recently, the two main coalitions (the Pan-blue and the Pan-green) have differed widely in their stances on Mainland China. Such disagreements have caused considerable turmoil and threaten

further development in Taiwan. Growing economic ties between China and Taiwan and significant Taiwanese capital in Mainland China have made previous unilateral political positions untenable.

We have identified increased legislative roadblocks and deteriorating macroeconomic policies (e.g., budget deficits) as key issues to be addressed. Recommendations for this issue are presented in the final section (Issue #4).

2.7. National Diamond

Factor conditions

Taiwan's favorable factors include a relatively young population and very good public education system, which produces over one million university graduates every year. Moreover, Taiwan's high ratio of high-school graduates undertaking vocational high-skilled training (70%) reflects great flexibility in skill development and training. The long history of being an open economy is also a plus.[16] The island's strategic location and its well developed infrastructure help to significantly reduce the transportation cost to its neighboring countries such as Japan, South Korea and China.[17]

Context for Firm Strategy and Rivalry

Taiwanese firms benefit from a highly-developed network of institutions for collaboration (IFCs), most importantly are the big universities that are located in key industrial area, for instance, Tsing-Hua National University and Chiao Tung National University located at the Hsinchu Science Park, and state-sponsored research institutes that play key roles in the economy, most notably is the Industrial Technology Research Institute (ITRI). The movement of workers between the state and corporate sectors and between large firms and small start-ups is very dynamic. It is not uncommon for ITRI to lend its staffs on a temporary basis to firms in research projects, and for ex-employees of large firms to set up their own firms. Also, there are strong informal networks of Tsing-Hua university graduates and ex-staff of state-sponsored institutes such as the ITRI, or industry leaders such as United Microelectronics Corporation (UMC) and Taiwan Semiconductor Manufacturing Corporation (TSMC), that facilitate the exchange of ideas within industries. [18] Taiwan also has many industry/cluster-based trade associations, formed out of both state and private initiatives. *(See Exhibit 2 for a list of prominent Institutes for Collaboration in Taiwan)*

[16] Ranis, G. (2002) "Lessons from Taiwan's Performance: Neither Miracle nor Crisis"
[17] Lall, S. (1998) "Exports of Manufactures by Developing Countries: Emerging Patterns of Trade and Location"
[18] From our own research and discussion with Taiwanese contacts and Chang, P. and Tsai, C. (2000), "Evolution of Technology Development Strategies for Taiwan's Semiconductor Industry: Formation of Research Consortia"

In terms of the role of the state, a benign government that acts swiftly to turn the economy at key junctions has enabled Taiwan to develop. The Taiwanese government has pursued coherent policies through trade liberalization and conservative fiscal and monetary policies. As the country abandoned import-substitution policies and exposed its domestic firms to international competition very early through export-promotion, Taiwanese firms were forced to become internationally competitive sooner than their competitors in other countries. The labor market was also liberalized considerably making it easy for firms to adjust quickly to changing market conditions. Not only does the government do a good job in keeping a healthy macro-economy, but it also establishes transparent regulation for competition. All in all, the government provided Taiwanese firms with a stable environment and fair playing ground to compete and develop. It also played an important stimulus role in directing and fostering basic research, although this role has diminished as private firms have been playing an increasing role in research since the 1980s.

On the negative side, recent corruption scandals have cast doubt on the stability of Taiwan political regime and the effectiveness of the government in conducting its economic policy. Moreover, Taiwan's weak judicial system is another significant holdback.

Demand conditions

Taiwan's large home market consists of relatively high income consumers. In addition, the government also assists businesses to get more market exposure through its sophisticated procurement of advanced-technology products (In 2006, Taiwan ranked third in the procurement of technology by the government).[19] However, electronics products, which make up a big portion of Taiwan's export goods basket, have been subject to price volatilities in the global semiconductor market. The volatile prices of semiconductor products are exacerbated by demand uncertainty from big electronics companies with vertically integrated manufacturing models. [20]

We propose one way in which Taiwan government, institutes for collaboration and firms could mitigate the negative impact of this volatility in demand. (Issue #5).

Related and Supporting Industries

Well-established domestic and international logistic firms in the economy support Taiwan's cluster-based industries. Taiwan is home to two international commercial airlines, China Airlines and EVA Air, and one of the world's largest containerized-freight shipping lines, Evergreen Marine Corporation. Moreover, besides several big companies in each cluster, this economy is rich

[19] Porter, M. (1998) "Building the Microeconomic Foundations of Prosperity"
[20] Tsai, Y., Wu, C. (2006) and HBS case TSMC, Page 3

in small and medium-sized companies which provide dynamics for innovation and a well-structured supporting industry chain.[21] Also, Taiwan's traditional venture capital industry has been a stable source of funding for small and medium-sized companies.[22] The availability of financing for start-ups promotes entrepreneurship and cluster development in various industries across the economy.

3. Cluster Analysis

The establishment of the Electronics Research and Service Organization (ERSO) arm of the ITRI in 1974 marked the beginning of tremendous growth of Taiwan's semiconductor industry. Success of the ERSO resulted in the spin-offs of UMC and TSMC, which are currently at the forefront of the global semiconductor industry and are both listed on the New York Stock Exchange. Taiwan's semiconductor industry has become very competitive in the worldwide semiconductor industry that experienced sales of $227.5 billion in 2005, a 6.8% increase from 2004 sales. In 2006, the Taiwan semiconductor industry generated 60% of worldwide IC revenue (for foundry, packaging and testing), 25% of worldwide DRAM revenue and another 25% of worldwide design revenue.[23] TSMC is currently the largest and most profitable foundry services supplier to the global IC industry.[24]

3.1 The ITRI and Institutes for Collaboration (IFCs)

The ITRI was established in 1973 by the Ministry of Economic Affairs (MoEA) as a national laboratory with the responsibility of developing technical capabilities for high-tech industries that the government had marked as strategic for Taiwan's development. As the ITRI undertook applied research, it accelerated industrial development by working closely with the private sector to ensure technology transfer from developed nations to domestic industries. With sponsorships from the MoEA, the ITRI conducted research that was shared with private firms. Also, the institute conducted specific research for individual firms on contract basis and formed R&D collaborations to update Taiwanese firms on best practices from technologies around the globe.[25]

The ITRI also facilitated the creation of new industries such as the fine chemicals, pharmaceuticals, optoelectronics and aerospace sectors. It also upgraded existing industries, many

[21] Aw, B. (2002) "Productivity Dynamics of Small and Medium Enterprises in Taiwan"
[22] Tang, M., Chyi, Y. (2005) "Law Environments, Venture Capital and the Total Factor Productivity Growth of Taiwan Manufacturing Industry"
[23] Overview on Taiwan Semiconductor Industry (2006), Taiwan Semiconductor Industry Association (Chutung, Hsinchu, Taiwan)
[24] Kintisheff Research, TSMC Analyst Report, April 10, 2007, via Thomson Research/Investext, accessed April 2007.
[25] Matthews, J. (1997) "A Silicon Valley of the East: Creating Taiwan's Semiconductor Industry"

of which were then able to support the new industries. By 1996, the ITRI budget had ballooned to $1 billion, about a third of which came from contract research fees from private firms. The rest came from the Taiwanese government. The ITRI maintains a portfolio of patents and operates a venture capital fund to incubate new technology companies.[26] Such contributions highlight the importance of the ITRI to the development of Taiwan's semiconductor industry.

3.2 Science Parks

In 1978, the National Science Council organized a national science and technology conference under the auspices of the Taiwan government. It was at this conference that Minister K.T. Li and other conference participants modeled the Hsinchu Science Park after California's Silicon Valley. Just as Silicon Valley thrived because of the rich interaction between the universities and private firms in the San Francisco Bay area, Hsinchu was located near Taiwan's best technical universities, Chiaotung and Tsinghua, and the ITRI (which had become the engine of the nation's technology growth). The park was deliberately set up to enable private firms to interact among themselves and the universities and research institutes in the area. The objective was to make it easy for Taiwanese firms to leverage and quickly master technologies from around the world.[27]

The government-owned Hsinchu provided firms that chose to locate there tax benefits, low-interest loans, R&D matching funds, investment allowances, tariff exemptions and other incentives. Locating in Hsinchu improved the credit profile of private firms and made it easier for those firms to access bank loans. Unlike similar parks found in Singapore and Malaysia, Hsinchu attracted mainly local home-grown Taiwanese firms many of which have grown to become major global technology companies. With improved facilities including medical services and educational centers, most of the private firms in Hsinchu attracted Chinese-Americans from top jobs in the U.S. and encouraged "reverse brain drain" as Taiwanese professionals from the U.S. found opportunities in Taiwan and helped establish the semiconductor industry. The government ensured minimal interference as private firms thrived in Hsinchu.[28] After Hsinchu, additional parks developed in Taiwan include the Southern Taiwan and the Central Taiwan Science Park.

[26] Ibid., p. 31.
[27] Ibid., p. 30-31.
[28] Ibid., p. 30-31.

3.3 Developmental Stages of the Semiconductor Industry

Taiwan's semiconductor industry has transitioned through three main stages of growth. The ***preparatory and seeding stage*** started in the 1960s when Taiwan positioned its economy for export-led growth mainly through small and medium private firms involved in contract manufacturing relations with U.S. and European manufacturing firms. Through the establishment of an export processing zone in 1965, Taiwan attracted contracts from US electronics and semiconductor firms seeking to invest in low-cost manufacturing in Asia as the worldwide IC market sales soared. In 1966, US-based General Instrument Microelectronics established a semiconductor packaging business in Taiwan and became the first semiconductor company there.[29]

By the 1970s, the seeding phase had taken roots as Taiwan was successfully transferring global technologies into capabilities in its semiconductor industry. The ITRI played significant roles in technology developments. The ERSO was subsequently formed out of the ITRI and charged by the government to promote technology transfer from the world's best into Taiwan. The government enacted Phase I of the Electronic Industry Development Project in this era which closed with ITRI/ERSO spinning out its pilot plant into the private sector, resulting in the creation of UMC in 1980. [30]

Taiwan's semiconductor industry went through the ***diffusion phase*** over the 1981-1990 period. With government sponsorship, technologies and new products were diffused to private firms that took on an increasing role to grow the domestic industry. Phase II of the Electronic Industry Development Project was enacted in this period to promote strategic growth of the industry. Various companies including TSMC were spun out of ITRI/ERSO during this era. In addition, several firms such as Syntek and Weltrend, which are IC design houses, were also founded by employees who had left ITRI/ERSO. By the end of this phase, an immature industry cluster had emerged with firms engaged in design, masking, fabrication and assembly.[31]

The semiconductor industry experienced the ***burgeoning phase*** over the subsequent decade following the diffusion phase. Competitiveness in the industry greatly increased along with a rise in prominence of Taiwan's semiconductor industry at the global level. An increased partnership between government and industry increased the role of private firms in the industry. By 1995 the cluster was fully developed with over 180 firms and had a large share of the world market. By 1999, Taiwan's semiconductor output exceeded $5 billion, making it the fourth largest producer in

[29] Chang, Pao-Long and Tsai, Chien-Tzu (2000), p. 185.
[30] Matthews, J. (1997) "A Silicon Valley of the East: Creating Taiwan's Semiconductor Industry", p. 33-34.
[31] Ibid., p. 34-35.

the world ahead of industrial giants such as France and the UK. The private firms became more collaborative even as competition among them increased. [32]

3.4 Historical Performance and Growth of Taiwan's Semiconductor cluster

While highly volatile, Taiwan's semiconductor revenues have grown rapidly and maintained relatively high margins. Revenues for the cluster reached $29 billion in 2005 with a margin of 14%. However, margins have fluctuated between -5% and 22%, reflecting the volatile nature of pricing in the global industry and Taiwan's relatively weak price-setting power. [33] Fabrication, which generates most of the revenues in the industry, doubled from about NT$300 in 2001 to NT$600 in 2004. Other aspects of the industry including fabless, packing and testing also showed consistent growth. However, growth in fabrication declined sharply in 2005, and growth in design was only lackluster.[34]

We have identified the volatility of semiconductor revenues and margins as a key issue to be addressed. Recommendations for this issue are presented in the final section (Issue #5).

A few firms have emerged as dominant players in Taiwan's semiconductor industry and garnered high market shares. These include TSMC (25%), UMC (10%) and Advanced Semiconductor Engineering (8%). However, several new players have emerged, diffusing the level of concentration of firms in the industry.[35]

Despite its small size, Taiwan ranks far ahead of other countries in semiconductor patents. The country currently surpasses Germany, South Korea and Malaysia in the number of semiconductor patents released annually. Also, the diversification of the patents has become more evenly distributed over time, moving away from semiconductor manufacturing processes. In 2005, electrical connectors and active state devices produced about the same number of patents as semiconductor manufacturing processes. However, total semiconductor patent production in Taiwan has declined recently, raising issues of concern.[36]

The following chart shows patent registration data of Taiwan semiconductor industry in the past 10 years. We can see clearly that patent registration increased at a remarkable rate in 1997 – 2001, but then there is a sharp decline after 2001. This cannot be explained by the lag time of patent registration since any such lag time should apply for all time periods. One feasible

[32] Johnston,C. (2000) "Taiwan Semiconductor Manufacturing Company and Matthews, J. (1997), "Silicon Valley of the East"
[33] Data on 190 semiconductor firms from Capital IQ database.
[34] IEK—IT IS Plan
[35] Data from Capital IQ.
[36] US Patent and Trademark Office, Electronic Information Products Division, Patent Technology Monitoring Branch (PTMB).

explanation could be that Taiwan firms have come to a plateau in terms of exploiting their existing knowledge base and had difficulties in mastering the newer technologies in semiconductors.

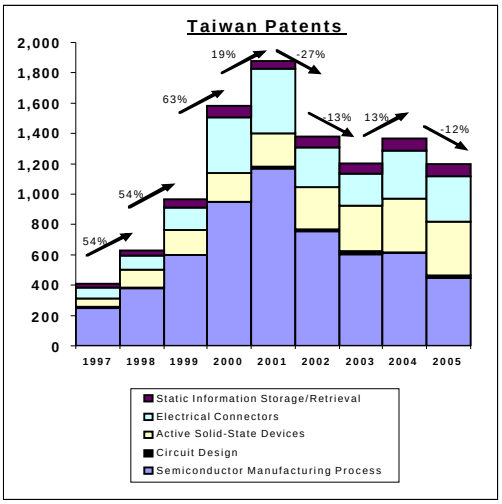


Table 11 - Source: US Patent and Trademark Office, Electronic Information Products Division, Patent Technology Monitoring Branch (PTMB).

We have identified this decline in semiconductor patents as a key issue to be addressed. Recommendations for this issue are presented in the final section (Issue #6).

3.5 Taiwan's Semiconductor Cluster Diamond

Context Conditions

The key factors in Taiwan's semiconductor cluster diamond provide fertile ground for the growth and development of the industry. Early involvement of the government to shape and develop the industry provided the nurturing needed to grow the industry in the 1970s and 1980s. Establishment of Hsinchu Science Park, ITRI, ERSO and other facilities, institutions and infrastructure encouraged private firms to move into the industry and enabled them to thrive. Furthermore, computerized operations of government agencies and public and private enterprises greatly increased the level and sophistication of domestic demand. Several government-supported IFCs enhanced collaboration among private and public sector, provided financing and other resources for the semiconductor industry, and encouraged technology development and distribution to various industry players.

However, the private sector has been increasing its role in the industry since the 1980s. For instance, individual firms, including typical fabricators and IC designers, have increased commitments to R&D investments to about 6-12% of sales.[37] While Taiwanese firms are

[37] Chang, P. and Tsai, C. (2000), "Evolution of Technology Development Strategies for Taiwan's Semiconductor Industry: Formation of Research Consortia"

competitive, collaboration among private firms thrives in areas where investment is necessary but risky. This is a shift from the early phase of the industry when government provided most of the R&D that mainly targeted research deemed risky. Private firms now form consortiums to share investment costs in risky technology research.

An example of this is the consortium established to pursue the Submicron Project from 1990 to 1996. This was a NT$7billion collaborative initiative involving several firms (including UMC, TSMC, Winbond, Macronix and Holtek) to research submicron technology for the participants. Upon successful completion of the project, member firms gained access to the new technology while the ITRI lab involved was spun off to form a new firm, Vanguard International Semiconductor. The success of this initiative encouraged the commissioning of the DEEP Submicron Joint Development Project as a follow on consortium project.[38]

Changes in the nature of semiconductor R&D reflected in the government's retreat from certain areas of research and the plethora of small firms have made it difficult for effective collaboration between the government, industry and universities. Collaboration between government and the private sector has been relatively strong as highlighted in the development and growth of the semiconductor industry. Similarly, Taiwan is ranked 7th in the world for university/industry research collaboration, indicating strong collaboration between universities and the private sector.[39] However, recent shortage of resources such as engineers for the semiconductor industry, and a decline in patents indicate that a more concerted collaboration between all three groups (government, private sector and universities) is needed for the industry to remain viable and to develop further.

We have identified government-industry-university collaboration as a potential area of improvement. Recommendations for this issue are presented in the final section (Issue #7).

Demand Conditions

As Michael Porter argues, the composition and character of demand have a disproportionate effect on how companies perceive, interpret and respond to buyer needs[40]. Highly sophisticated demand from both local and foreign customers have provided a platform for higher productivity as private firms emerged in Taiwan without the benefit of protective tariffs and government subsidies. Three of the top ten global computer hardware manufacturing firms, namely Asustek, Quanta and Acer, are headquartered in Taiwan and generate sophisticated local demand for

[38] Chang, P. and Hsu, C. (1998), "The Development Strategies for Taiwan's Semiconductor Industry"
[39] Porter, M. (1998). "Building the Microeconomic Foundations of Prosperity: Findings from the Business Competitiveness Index ."
[40] Porter, M. (1990) "The Competitive Advantage of Nations"

semiconductor products[41]. Moreover, the Institute for Information Industry improves productivity and competitiveness of all industries through the use of IT and fosters collaborative competition among private firms. Taiwan's sophistication of demand is also exemplified by its ranking in terms of the info-use. Based on this statistic used by the International Telecommunications Union to measure consumption of Info-Comm Technologies flows per period, Taiwan is a world leader and has kept pace with other high info-use countries over the past decade.

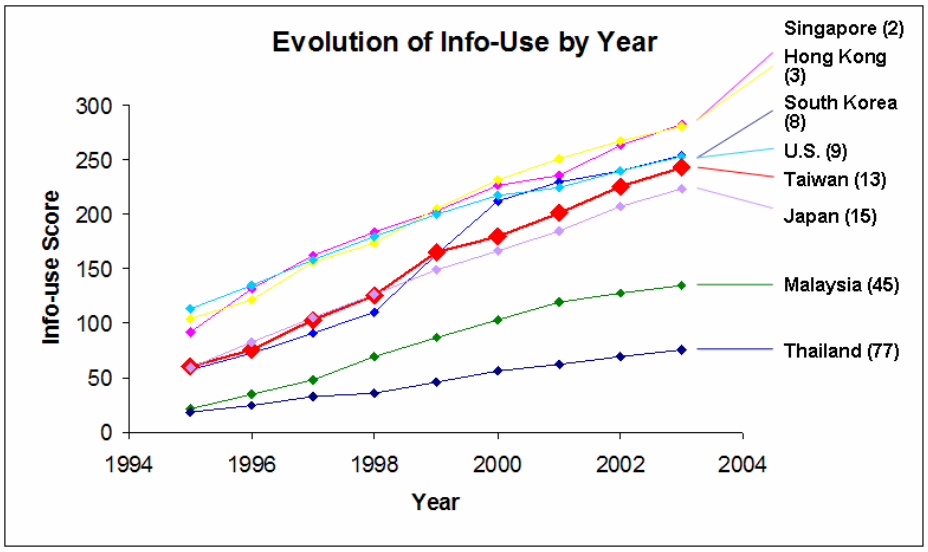


Table 12 - Source: International Telecommunication Union (ITU)/International Network of UNESCO Chairs in Communications (Orbicom), "ICT Opportunity Index", (2006)

Additionally, export-driven policies exposed Taiwan to sophisticated foreign demand in the early development stage of its semiconductor industry. With support from the ITRI, ERSO and other IFCs, private firms in the cluster learned to become more productive and efficient enough to compete in the global semiconductor market. Taiwan's sales of semiconductor products have experienced tremendous growth driven by expansion of overseas markets. As global demand for consumer electronics such as mobile phones and LCD TVs have surged in an era of strong economic growth in emerging markets, both the quantity and quality of demand have increased.

Since 2002, exports have exceeded domestic semiconductor products sales due to direct shipments to Taiwanese system assembly lines in Mainland China. Mainland China has become main export destination because it is a major global assembly base for electronics products.

[41] Data from Capital IQ

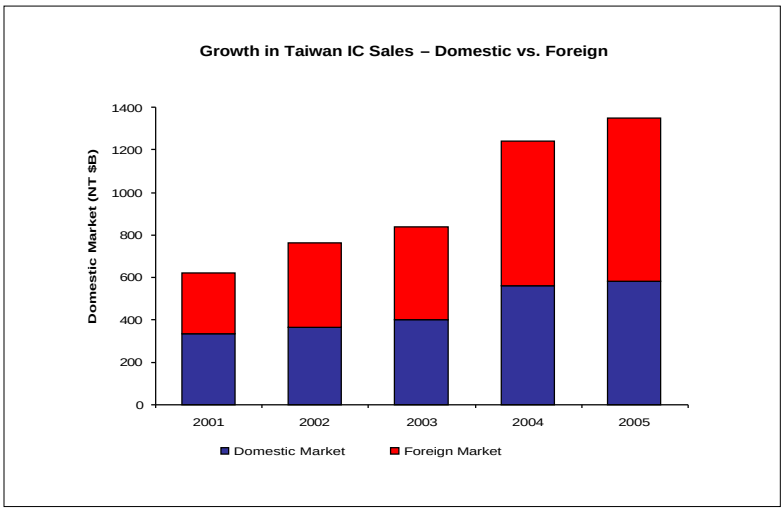


Table 13 - Source: Overview on Taiwan Semiconductor Industry (2006)

Factor Conditions

Taiwan's semiconductor industry has also benefited from the high availability of scientists and engineers and a well developed local venture capital industry. Taiwan has a high density of universities and a growing student population. It currently has over 50 universities, including several highly respected science research centers. University enrollment has doubled in the last five years and is growing in technical fields. However, it is estimated that Taiwan's universities will be unable to satisfy industry demand for engineers and designers in future years.[42] While the number of R&D personnel in Taiwan per 1000 persons exceeds that of Mainland China and India, it still significantly lags the penetration found in other developed countries such as Japan and Sweden[43]. This labor supply problem is exacerbated by the fact that rising wages are causing Taiwanese firms to migrate across the Strait in search of cheaper labor

We have identified competition for works and labor supply issues as a serious threat facing Taiwan. Recommendations for this issue are presented in the final section (Issue #8).

Related and Supporting Industries

Taiwan has a highly diversified and world-class set of industries that support its semiconductor industry. Most of these industries are significant in Taiwan's economy as ranked by revenues of public firms. In 2006, the computer and electronics hardware, manufacturing services, communications equipment, chemicals, finance, distribution and logistics industries contributed

[42] Taiwan's Ministry of Education.

[43] Hung, S., Yang, S., Lee, C. (2004) "The Vertical Disintegration of Taiwan's Semiconductor Industries: Price and Non-Price Factors"

significantly to the nation's economy as ranked by revenues of public firms[44]. Chemicals and packaging industries are well established, and the IC design sector is highly sophisticated. Also, the logistics sector is highly developed to facilitate shipment of goods. The related and supporting industries provide necessary resources and infrastructure that enable the semiconductor industry to become productive and competitive.

Competition among Private Firms

Although private firms in Taiwan's semiconductor industry have learned to collaborate in key areas such as risky and expensive R&D, they compete against one another to improve upon technologies developed through the collaborative process. Thus, despite the availability of technologies through the ITRI to various private firms in Taiwan's semiconductor industry, TSMC and UMC have emerged as global leaders in terms of manufacturing cycle time, on-time delivery, wafer throughput, and yields for logic devices. The two industry leaders have also pursued slightly different strategies: TSMC has remained a pure-play foundry but UMC is positioning itself to become an integrated company.[45] Moreover, during the 1990s UMC and TSMC independently developed their own world-class 0.6μm processes using ITRI-transferred technology.[46]

Despite the competitive position of Taiwan's semiconductor industry at the global level, increasing labor costs are creating a competitive disadvantage in the sector. Private firms have been moving some operations to Mainland China to reduce costs.

4. Issues and Challenges

4.1. Key Issues and Recommendations

Our study of Taiwan and its semiconductor cluster has unearthed a number of critical and strategic issues that must be addressed. We have identified the following eight priority issues: (i) political tension between Taiwan and Mainland China, (ii) over-reliance on a few export markets, (iii) underdeveloped institutions, (iv) legislative roadblocks and macroeconomic policy risks (v) volatility in semiconductor revenues and margins, (vi) a drop in semiconductor patents, (vii) imperfect university-government-industry coordination, and (viii) a skilled labor supply shortage.

[44] Based on data from Capital IQ

[45] Leachman, R. C. and Leachman, C.H.(2000) "E Commerce and the Changing Terms of Competition in the Semiconductor Industry".

[46] Chang, P. and Tsai, C. (1998) "Evolution of Technology Development Strategies for Taiwan's Semiconductor Industry: Formation of Research Consortia"

The following sections draw from and synthesize the previous analysis and present recommendations for the aforementioned eight priority issues.

4.1.1. Political Tension with Mainland China

Taiwan's tenuous relationship with Mainland China has become an increasing concern, with both sides engaging in political and military showmanship. The Taiwan-Mainland issue is an intractable concern that threatens the former country's political stability and may indeed prevent Taiwan from progressing. While we do not pretend to solve the diplomatic issues between Taiwan and Mainland China, there are some practical steps that the Taiwanese government and business community can take. **Taiwan must clearly define a symbiotic relationship with the Mainland**.

Firms	IFCs	Government
Once the government has set-up a Taiwan-Mainland taskforce (described later), firms must coordinate their activities through the government taskforce to mitigate tensions. Working together with this dual-country taskforce may help alleviate diplomatic concerns that filter down and affect day-to-day business decisions.	IFCs in Taiwan and Mainland China should form joint committees and programs to build trust and engage in joint decision-making and industry promotion.	Taiwan's government should develop a more substantive taskforce that addresses Taiwan-Mainland relations. Current diplomatic missions do not seem to be achieving measurable, practical results.

4.1.2. Over-Reliance on a Few Export Markets

As has already been pointed out, Taiwan relies on two key markets for its exports – both overall exports and electronics exports. The United States accounts for 20% of Taiwan's overall exports and electronics exports. China, including both the Mainland and Hong Kong account for 36% of Taiwan's overall exports and 32% of the country's electronics exports.[47]

There are two key issues that arise with Taiwan's level of export concentration. First, such concentration subjects the country to considerable terms-of-trade risks, including the possibility of competitive devaluation and contagion. Secondly, Taiwan's increasing reliance on Mainland China as an export market may lower its bargaining power vis-à-vis other political and economic relations with the Mainland. As such, our recommendations center on the idea of **diversifying Taiwan's export markets**.

[47] World Trade Organization.

Firms	IFCs	Government
Firms should intensify marketing efforts in new countries – especially in Europe where Taiwanese firms have less of a presence. Global marketing and sales offices or joint ventures would be a positive start.	Taiwanese semiconductor IFCs should collaborate with IFCs in other countries and regions to foster global trade. This can be achieved through global forums or formal linkages of organizations.	Taiwan's government should enter into as many bilateral trade agreements as possible. Bilateral agreements, while a second-best option, may be Taiwan's only choice given the political pressure from Mainland China.

4.1.3. Under-Developed Institutions

Taiwan has a weak judiciary and has suffered from corruption at the central government level over the past decade. Government corruption scandals have, for example, hit Chao Chien-ming, the current president's son-in-law who has been jailed, Wu Shu-chen, the country's first lady, and Ma Ying-jeou the leading opposition candidate and former mayor of Taipei. Scandals have also rocked Taiwan's business community, including three executives of Chinatrust, a major bank, and 107 executives from Rebar Group, a major conglomerate.[48]

Corruption erodes confidence in the government and in business, undermining key public and private sector institutions and stymieing economic development. Taiwan should **improve functioning of its judiciary and launch anti-corruption campaigns**

Firms	IFCs	Government
Firms should strictly enforce internal anti-corruption policies	IFCs must develop anti-corruption policies and "police" firms to ensure enforcement	Government should reform its legal/judiciary and anti-corruption institutions to meet global standards. Also, the Government must promote greater transparency in legislation, policy formulation and licensing approval

4.1.4. Legislative Roadblocks and Macroeconomic Policy

Taiwan has traditionally had sound macroeconomic policies, but multi-party democracy has had the impact of creating legislative roadblocks. For example, in January of 2007 the parliament failed to pass an annual budget – the first time such an event has ever occurred. This, as well as a series of other failed legislative actions, highlights the limitations in implementing policy changes in a bitterly opposed and hostile parliament.[49] In addition, the government has run a budget deficit

[48] Dean, J. and Piling, C. "Corruption Trials Captivate Taiwanese," *The Wall Street Journal*, April 12, 2007.
[49] Economist Intelligence Unit. *Country Report: Taiwan*, February 2007.

for a number of years. **Government must reverse the budget deficit and create mechanisms for improved legislative coordination.**

Firms	Government
Firms should lobby government to maintain fiscal and monetary discipline	Government should cut spending or raise taxes to balance its budget; must also reform legislative processes

4.1.5. Volatility in Semiconductor Sales and Margins

Taiwanese manufacturers are subject to the swings in semiconductor product prices and lack price-setting power. For example, from 1997-2005, semiconductor firms' margins averaged 13% with an annual volatility of about 10%.[50] The government's and firms' effective "over-allocation" to semiconductors makes them susceptible to sharp price declines that may inhibit both parties' ability to finance existing or future growth plans. **Taiwan should use financial engineering to mitigate the industry's price volatility**

Firms	IFCs	Government
Firms should better manage their risks using financial derivatives.	IFCs should promote the understanding and use of financial derivatives.	Government should further develop financial markets and enter into total return swap exchanging semiconductor for world returns.[51]

4.1.6. Drop in Patents

As shown previously, Taiwan has been a leading issuer of semiconductor patents, lagging only the U.S. On a per capita basis, Taiwan is the world's leader in semiconductor patents registered in the United States. Despite its leading position, Taiwan's semiconductor patenting intensity has declined markedly: from approximately 1,900 semiconductor patents in 2001 to about 1,200 in 2005. The decline has been particularly noticeable in the "semiconductor manufacturing process" category, where annual patent grants have declined from 1,200 to 500 over the same time period.[52]

The drop in manufacturing process patents and innovation threatens the growth of the semiconductor fabrication industry – and which may explain the recent leveling-off in Taiwanese semiconductor fabrication revenues. There is also a concern that the quality of patents has declined

[50] Based on data on 190 Taiwanese semiconductor firms collected from the Capital IQ database.
[51] This is an idea that has been developed by Professor Robert Merton at the Harvard Business School and has been presented, among other forums, as part of this graduate-level Functional and Strategic Finance class.
[52] United States Patent and Trademark Office, Electronic Information Products Division, Patent Technology Monitoring Branch.

over time. While there is no concrete way to measure patent quality, industry experts see patent quality erosion as a serious threat.

Part of the problem in Taiwan is that smaller firms have been reluctant to invest in innovation, preferring the route of joint or collaborative research and development. While collaborative R&D is worthwhile pursuing, it should not come at the expense of original firm-specific research. In general, our recommendation is that **Taiwanese firms and Taiwan's government increase R&D spending**.

Firms	IFCs	Government
Firms should increase their individual R&D spending for independent, applied projects. A reconsideration of cost-of-capital hurdles or growth potential is in order.	IFCs can play a critical role in ensuring that the Taiwanese semiconductor industry continues to be involved in collaborative and "high risk" research projects – especially for smaller firms. These projects should follow past successes in this area (e.g., Submicron and DEEP Submicron Projects).	The Government has recently pulled back from doing semiconductor R&D. This makes sense at this point. However, now that it is no longer involved in R&D the government needs to reconsider how its can improve firm incentives to take on R&D projects. The government should remain active in primary science research.

4.1.7. Imperfect government-university-corporate coordination

While Taiwan has good industry/academic research coordination, the government is not doing enough to promote basic research and creating research for future innovation. In addition, while some industry-university collaboration already exists, Taiwan should further strengthen such initiatives to build a competitive edge in this area. **Taiwan should address changing industry needs for human capital and research by better coordinating with universities**

Firms	IFCs	Government
Firms must identify areas of future needs and fund university programs in these disciplines	IFCs should pool the interests of businesses, especially SMEs, to coordinate academic research and education	Government should increase research funding for basic sciences and "risky" research and provide financial aid to science students

4.1.8 Competition and Labor Supply

As with most successful industries that see significant increases in productivity, Taiwan's semiconductor cluster has seen an increase in wages for a range of technical jobs. Given the competitiveness of the semiconductor industry it is unclear whether future wage increases can be

passed along to consumers or whether Taiwan's industry positioning will suffer. In the United States, the average experienced electrical engineer earns about US$82,000. The same engineer in Taiwan earns US$30,000. This relative wage discrepancy has helped make Taiwan globally competitive. However, an electrical engineer's wages in China and India are $12,000 and $15,000 respectively – creating considerable pressure for Taiwan.[53] Labor cost increases have caused fabrication to move out of Taiwan; and U.S. firms are bypassing Taiwan when they look to build new facilities abroad. A good example of this is Intel which recently chose Mainland China over Taiwan as the location for a new wafer plant. Engineering wage increases also threaten Taiwan's dynamic domestic chip design industry.

Our findings suggest that Taiwan needs to **promote cluster expansion across the Strait** to take advantage of the Mainland's cost advantage while at the same time bolstering domestic, higher value-added productive activities. We are also recommending that Taiwan **loosen its labor market** and immigration restrictions to attract foreign talent.

<table>
<tr><th>Firms</th><th>Government</th></tr>
<tr><td rowspan="2">Promote cluster expansion across the Strait
Firms should seize the opportunity of building closer relations with the Mainland by moving low cost and lower value-added and less productive manufacturing activities to the Mainland, while retaining domestic activities higher up in the value chain.</td><td>Promote cluster expansion across the Strait
Despite populist or business pressure, the government should resist any action to protect the local industry from low cost competition.</td></tr>
<tr><td>Loosen labor market regulations
Government should deregulate labor markets to allow the inflow of engineering talent, especially from Mainland China, India and Russia. The requisite immigration laws may need to be altered.</td></tr>
</table>

5. Summary

Taiwan's remarkable growth since World War II has been catalyzed by the development of its electronics industry and the creation of a semiconductor cluster. Despite various disadvantages such as inadequate natural resources and tensions with Mainland China, the government fostered political stability and directed the economy appropriately towards high growth, making strategic

[53] Brown, C. and Linden, G. (2006). "Semiconductor Engineers in a Global Economy," *National Academy of Engineering, Workshop on the Offshoring of Engineering: Facts, Myths, Unknowns, and Implications*. October 25, 2006, Washington, DC.

changes from import-substitution to export-led growth when needed. The burgeoning Taiwanese semiconductor cluster highlights the successful creation of an industry from scratch through the dynamic interplay between government, private sector, IFCs and universities within sound institutional frameworks. Despite the significant role of government in the creation and nurturing of the semiconductor industry, the government realized that real prosperity is created by the private sector and so promoted a healthy balance of competition and collaboration among private firms to increase competitiveness and productivity of the cluster. Also, IFCs, universities and supporting industries contributed meaningfully to the development of the cluster. Taiwan's "miraculous growth" shows that government can play a leading role in cluster development but must understand its role and not overstep its boundaries to hinder others from playing their roles effectively.

Another intriguing aspect of the success of Taiwan's semiconductor cluster development is its reliance on domestic capital rather than FDI. Given that FDI flows have increased significantly over time and are considered an integral part of "the globalization of competition and the global specialization of value chains," more research is needed to understand the role of FDI versus domestic capital in economic growth, competitiveness and formation of industry clusters.[54] The results of such research may shape nation's policies regarding the use of FDI or domestic capital in strategizing for economic growth and cause Taiwan to reconsider use of FDI to further grow its cluster.

[54] Michael Porter, "Attracting Foreign Investment: A Competitive Perspective"

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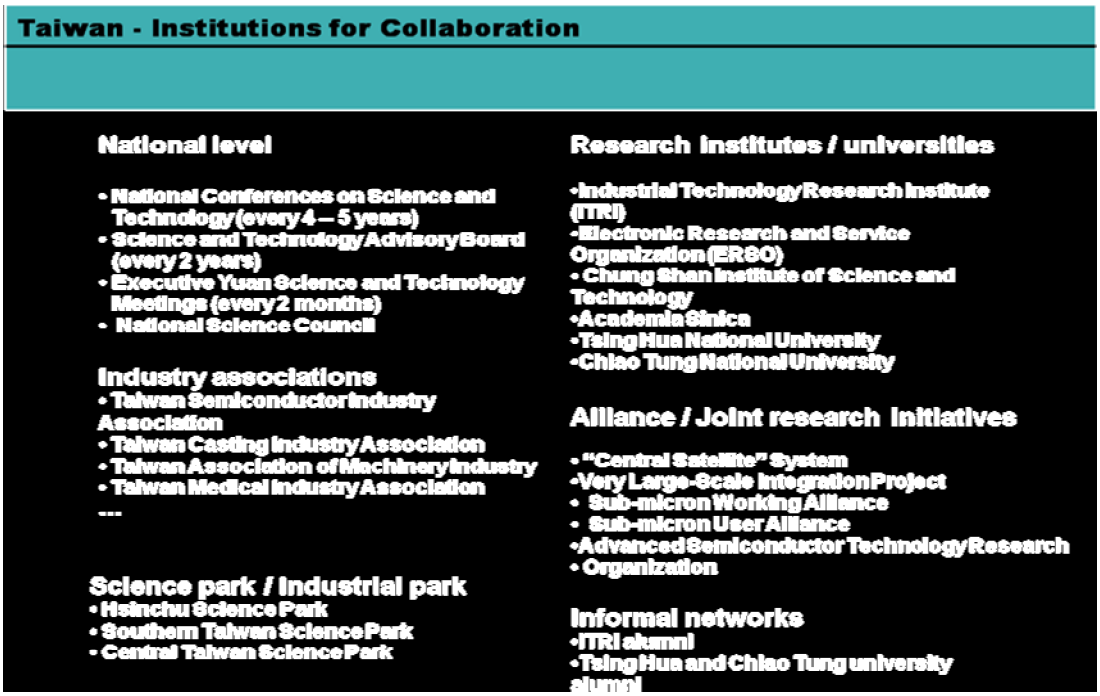
Exhibit 1

Economic evolution: Growth Over 3 decades

	1949 – 1962	1962 – 1980	1980 – Present
Broad Economic Strategy	• Commodity production • Light industry exports • Import substitution	• Export promotion • Export Processing Zones (EPZs)	• Focus on knowledge - based industries • Science Parks developed • Trademark and patent laws strengthened
Other Key Economic Developments	• Land distribution • Privatization of SOEs • Fixed exchange rate promoted exports	• "Ten Major Construction Projects" • National Science Council • Liberalization of import controls and lowering of tariffs	• ITRI begins technology diffusion role • Adoption of labor standard law
Key Political Developments	• KMT consolidates power • US aid and defense provision • Local multi -party elections	• Chiang Kai -shek's son in power, begins reforms	• Opposition party (1986) • Martial law lifted (1987) • End of KMT rule (2000)
Key Social Developments	• 2 million Chinese immigrate from mainland	• Family planning encouraged	• General social liberalization

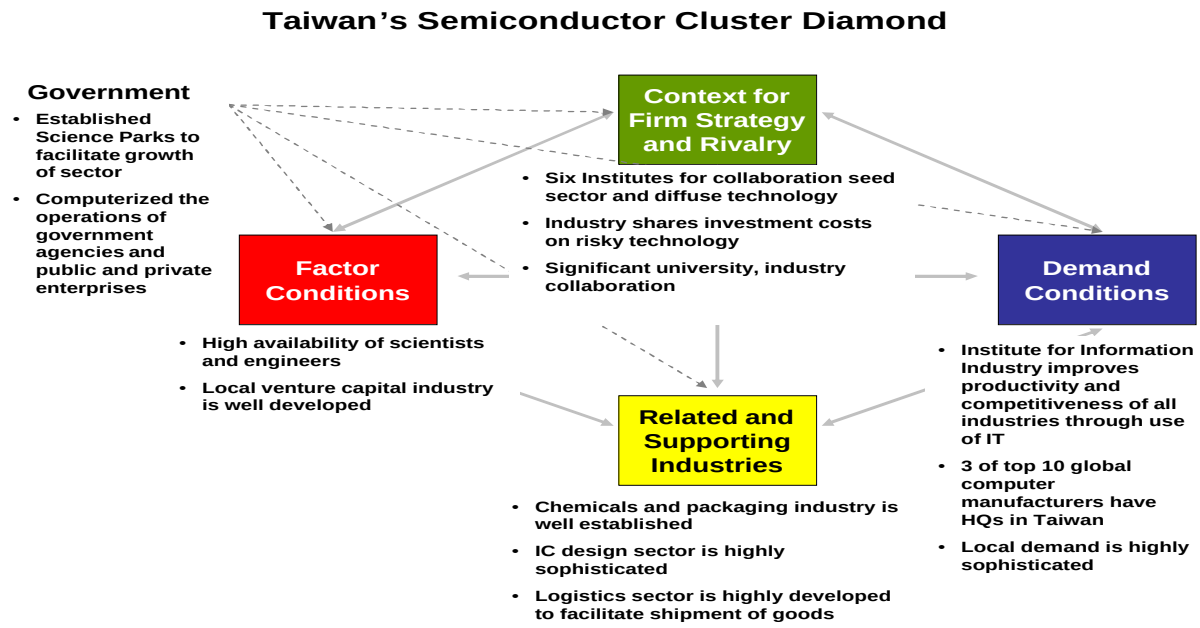
Source: K.T. Li, "The Evolution of Policy Behind Taiwan's Development Success", Yale University Press, 1998

Exhibit 2



Source: Our research and Chang, Pao-Long and Tsai, Chien-Tzu (2000), "Evolution of Technology Development Strategies for Taiwan's Semiconductor Industry: Formation of Research Consortia", *Industry and Innovation*, Vol. 7, No. 2, December 2002.

Exhibit 3



Source: Source: John A. Matthews "A Silicon Valley of the East: Creating Taiwan's Semiconductor Industry", California Management Review (1997); Pao-Long Chang and Chiung-Wen Hsu, "The Development Strategies for Taiwan's Semiconductor Industry", IEEE Transactions on Engineering Management, Nov 1998 .