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An Evolutionary Perspective of IC Industry Development in Taiwan

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Abstract

Taiwan has successfully developed an IC industry through the efforts of the government and industry itself over the past thirty years. One of key factors that decades of rapid and continuous economic growth and prosperity was driven prominently by the development of an IC industry to let Taiwanese being proud of it. The purpose of this research is to explore the development track of IC industry to know how it worked. This paper reviews the development and transformation process of IC industry in Taiwan. This process will be examined from the longitudinal aspects through synthesizing the literature reviews and observations. It is categorized by three stages: labor-intensive stage, technology-intensive stage and capital-intensive stage for analysis. This study showed that a far-sighted strategy to establish a sound infrastructure of industrial development environment is necessary and sufficient for an emerging new industry especially for high technology. This paper found that the silicon technology cycle in Taiwan is seven years. The closed and dynamic networking relationship among government, university, industry and foreign leaders is instrumental in developing the IC industry in Taiwan.

Keywords: IC industry, Industry Development, Technology Transfer, Technology Formation, Strategic Alliance.

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Introduction

Characteristics of IC industry

The silicon-based semiconductor is an electronic device that allows data, voice and video processing. These discrete electronic devices are formed into ICs (Integrated Circuits) for application in various systems. The IC is usually called “the rice of industry”. The IC sector is responsible for dramatic decrease in cost and increase in performance of electronic systems in the past, present and future. Following the observation of Mr. Gordon Moore (one of the three founders of Intel Corporation, USA) proposed in 1965 (http:/ www.intel.com) that the data storage capacity of memory devices would double every 12 months, has now become enshrined as “Moore’s Law”. Gordon Moore’s dictum is usually cited as “the number of transistors in an IC will double every 18 months and its cost will be cut in half. This has fueled exponential trend in IC technology that propelled the adoption of ICs into an ever-expanding array of applications in all industries.

The IC industry is quite different from other industries. Over the past 30 years, some special characteristics in the IC industry have been revealed. The set of factors unique to IC manufacturing includes (Sattle and Sohoni, 1999):

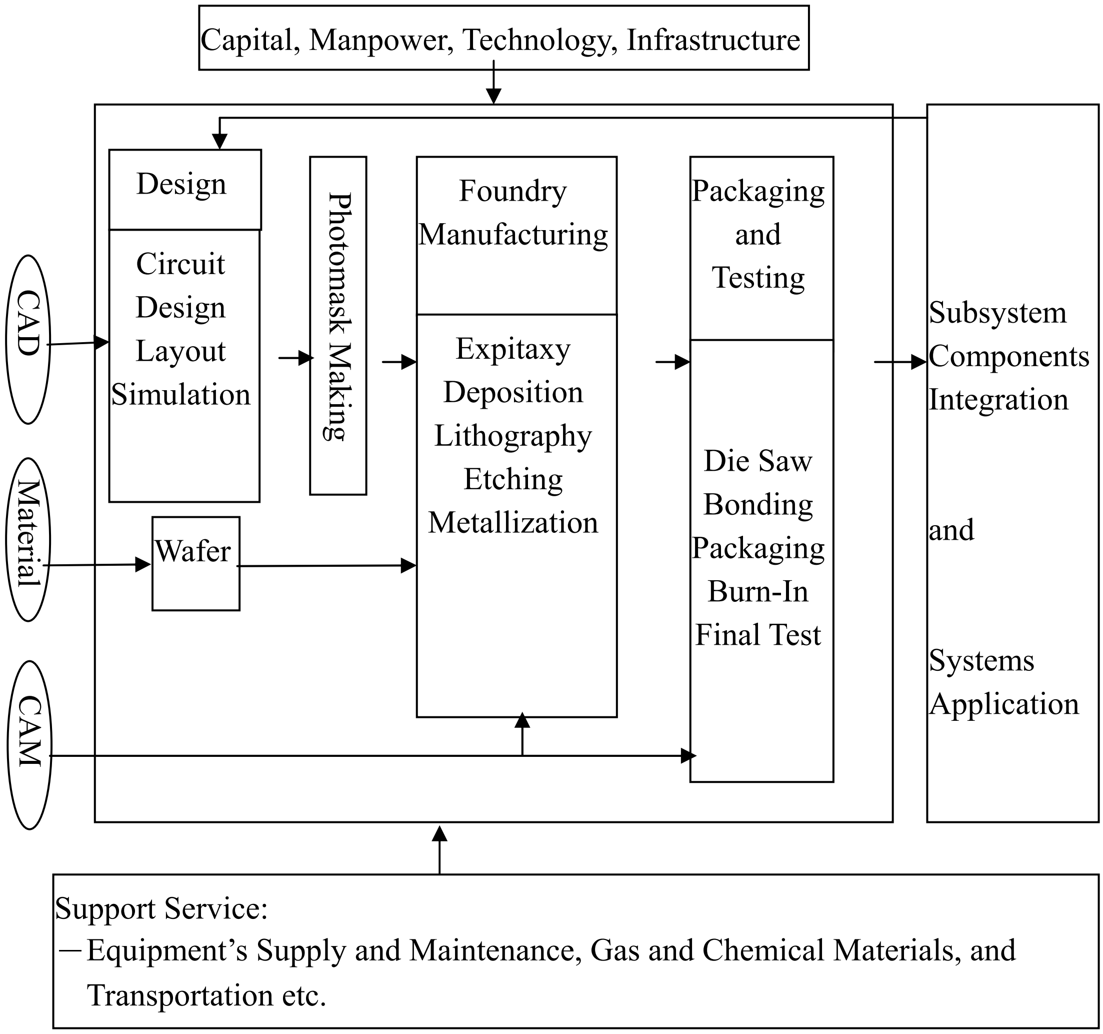
- An uncertain and highly complex manufacturing process
- Short product life cycles
- Contamination and yield problems
- Complicated product flows
- Difficulties in acquiring human capital
- Time-consuming equipment problems

Over the past decades, IC industry has become the driving force in this crucial endeavor, ushering a remarkable epoch. Rising and falling of silicon cycle influence the economic state of industry. The development of IC industry has certainly set the tone of interventionist policies that aimed at its national competitive positions in the strategic industry.

Structure of IC industry

IC industry has many of unique and unusual characteristics related to high technology industries. It covers the fields of electronics, materials, chemistry, chemical engineering, and automatic control and information systems. The structure in the IC industry system is composed of product planning, circuit design, circuit layout, circuit simulation, photomask making, frontend manufacturing (foundry), backend manufacturing (packing and testing), materials and equipment supply, as shown in Figure 1. Some of elements in the value chain of structure are divided or integrated into many sub-industries such as: the design industry, photomask industry, wafer supply industry, foundry industry, and chemical materials supply industry, gas

Figure 1
Structure of IC Industry Systems



*This figure is revised from ITIS Project Report, ERSO/ITRI, 1998

supply industry, front-end equipment supply industry, CAD/CAM (Computer-aid-design /Computer -aid-manufacturing) software industry, packaging industry, testing industry and backend equipment supply industry. In summary, all of these sub-industries are called the IC industry.

Worldwide IC industry

1. US IC industry

The integrated circuit was invented by Robert Noyce of Fairchild Company and Jack Kilby of Texas Instruments in 1958, and put into commercial production in 1961 (Moris, 1996). Today, many electronic components are based on IC technology and thus are also affected by the development of the IC industry in the United States. US semiconductor companies are major players both in the electronics industry and the global economy. According to the report of SIA (Semiconductor Industry Association) in 1994, US companies controlled 50% of the European market, 40% of the Asia/Pacific market and 17% of the Japanese market.

The US has the largest IC production base and consumer market in the world. The lead of the US in the IC industry means, it inevitably dominates the development of the global IC industry, a trend that is likely to continue to be true in the future. Giant US-based companies outperformed in both business operations and technological development in IC and thus dominated the global IC industry, with examples including Intel, Motorola, IBM (International Business Machine), Micron, TI (Texas Instruments), Lucent etc. Over the past decades, the US semiconductor industry has embarked on a number of programs encouraging and facilitating cooperation and focused research. For example, SEMATECH (SEmiconductor MAnufacturing TECHnology) Inc., SRC (Semiconductor Research Corp.), and other public- and private sector initiatives have helped American chipmakers to hold their own and even gain ground in the face of broad international competition.

One reason for the ability of the US IC industry to maintain a strong position is its heavy and continuous investment in research and development, which has activated a flourishing related industry not only from upstream to downstream and but also from device or component to systems. Another strength of the US IC industry is the availability of sufficient capitals through the boom in venture capital investment. Venture capital funds encourage new start-up companies or seed technical teams to support cash flow and thus reduce risk during the initial steps before time-to-market stages of technology development. The US led the global electronic industry for several decades. These characteristics clearly demonstrated the natural advantages of the US. One such advantage is an education system that encourages student creativity. This creativity serves as a basis for new technologies and products, and in turn for strong competitiveness and core competence. The US lost the its position as the largest IC market in the world to the Asia Pacific region in 2001, with IC sales in the US declining from US$204 billion in 2000 with a 31.3% share of the global market, to US$139 billion in 2001 with a 25.8% share of the global market (IEK/ITRI, 2002). However, despite this relative decline, the US market continued to lead global supply and demand. The US has advantages of a huge internal market, industry clustering, an innovation culture, a lead in advanced technologies and de facto standards, and a well-defined infrastructure. Well- known US companies maintain a strong position, having significant repercussions on the global IC industry development.

The US IC industry is renowned for its record of technological breakthroughs. These advanced have increased the speed and capabilities of computer chip and led to employment growth in the industry that runs against the grain of recent US manufacturing history (Moris, 1996). The US IC industry should continue to develop high added-on-value products and conduct technological research and development to increase the gap between it and Asian imitators. Reducing manufacturing costs and investment risk through foundry or OEM (Original Equipment Manufacturer) to align with the world trend of vertical disintegration is one method of preventing other companies from challenging the US leaders.

The US IC industry has had a profound and lasting impact on the development of the Taiwanese IC industry since the 1970s. Taiwan first transferred CMOS (Complementary Metal Oxide Semiconductor) process technology from a US company: RCA (Radio Corporation of America) in 1970s, and then went on to extraordinary successes during the 1980s, 1990s, and even 2000s. The IC industry and related technologies were successfully developed and learned on the basis of this technology transfer and diffusion although the education and training environments in Taiwan was inferior to that in the US. Made-in- Taiwan IC products smoothly entered the US market, improving the Taiwan-American IC business relation, and accelerating the Taiwanese economic growth during the 1980s and 1990s. Taiwan will continue to require the technological support of the US, for the foreseeable future, based on the need to upgrade the technological level of its IC industry and enhance vertical disintegration between Taiwan and China.

2. Japanese IC industry

IC technologies were gradually transferred from the US to Japan after IC was invented in 1950s, and Japan enjoyed major achievements in the 1960s, 1970s, 1980s and subsequently. Japan licensed US semiconductor technology starting from the 1950s, and Sony Corporation produced the first semiconductor radio in 1955. IC technology began to be mass- produced in Japan in 1964 and three big Japanese companies: Fujitsu, Hitachi and NEC (Nippon Electrical Corporation) produced computers based on IC in 1965 (Lee, 1999). It opened the new era of prosperous development of Japanese IC industry.

The major ingredients for the success of Japan included government assistance, US technologies, significant R&D investment, and a strong technological background. Some 20 years ago, Japan established a VLSI (Very Large Scale IC) cooperative research institute under a joint consortium linking MITI (Ministry of Industrial Technology Institute) and semiconductor companies. The successful work of this group has enabled Japan to enter the front ranks of the global semiconductor industry. Japanese success in the IC industry has been attributed to the cooperative R&D program organized by MITI, in which companies share R&D results, a program that is coordinated and partially subsidized by the government. This program involved an extended expansion of R&D results and account for the commercial success. The history of the Japanese semiconductor industry illustrates the reliance on government agencies to coordinate, guide, and promote key industries, a tendency still evident today despite the lesser use of industry policy (Peck, 1997). The Japanese IC industry will find its global strategy universally applicable. International IC R&D infrastructure is needed to focus on fundamental or pre-competitive research and new material developments. The Japanese government's pre-emptive R&D policy is quite different from "targeting" industrial policy in a strict sense (Yoshitomi, 1994). The right positioning enables the Japanese IC industry to be developed successfully.

In the mid-1980s, Japan surpassed the United States in semiconductor production, but throughout the 1990s competition from Taiwan, Korea and Western nations intensified to the point where Japan-based companies now hold less than a 30 percent share of worldwide production (Hara, 2000). Japanese technology companies are following strategies similar to those of their American competitors, such as moving plants offshore to seek cheaper labor. Instead of friction, many US and Japanese firms are cooperatively pooling technical skills and capital (Haavind, 1995). This strategy is followed to be more competitive in the world market even after 2000.

Japan IC makers can benefit from Taiwan's cheap costs and the solid foundry support from UMC (United Microelectronics Corporation), TSMC (Taiwan Semiconductor Manufacturing Company), Winbond, Powerchip, Macronix and so on. Taiwan has increasing become a high technology outsourcing center for Japan since the bursting of the Japanese bubble economy occurred in the early 1990s. Struck hard by the national economic recession in the 1990s, many Japanese companies, including NEC, Fujitsu and Toshiba, engaged in consolidation, reengineering and project cut-off. Basically, most Japanese IC companies now adopt a foundry and outsourcing based strategy, transferring their production base offshore and establishing strategic alliances with sourcers. Taiwan thus has become an IC industry-outsourcing center for Japan. Strategic alliances with Taiwanese IC companies are a key industrial strategy helping Japanese IC companies to compete in the world market since the bursting of the Japanese bubble economy during the early 1990s.

Fierce competition occurred between Japanese and Taiwanese IC companies during the 1980s and 1990s because of both countries having the same level of wafer manufacturing technology and product function, and fighting for the same markets. However, this situation changed with the establishment of strategic alliances after around 1995 and even beyond 2000, with the shift of the advanced wafer technology from Japan to Taiwan.

3. European IC industry

European IC industry development lagged that of the US and Japan owing to a lack of resources to devote to the emerging IC industry in the wake of World War II, a lack of internal markets, and no government support or subsidies. However, Holland's Phillips was one significant IC company to emerge in Europe, during the

1970s, and it has generally ranked among the top ten in the global semiconductor industry. Besides Philips Company, both technology research and development centers and market scale are generally too discrete in European countries including England, France, Italy, German and Holland to be economically effective. This situation thus offered the chance for US and Japanese companies to set up wafer fabrication plants in Europe.

European semiconductor manufacturers have achieved significant progress recently in terms of competitiveness and market share. Much of this competitive success can be attributed to the pan-European pre-competitive R&D scheme MEDA (Micro-Electronics Development for European Applications). Over its four years of operations, the industry-initiated, government- supported program has executed 55 projects involving more than 150 partners in 12 countries, and cost about US$2 billion (Dance, 2001). The MEDA+ program will continue to run until 2008 in two successive four-year phases. Some 2500 researchers will be involved and the budget will be approximately US$470 million per year, keeping the European semiconductor industry competitive in the future. The four-year MEDA (Micro-Electronics Development of European Applications) program, which started in 1997 succeeded the eight-year JESSI (Joint European Sub-micron Silicon Initiative), which expired at the end of 1996. Despite some organizational, financial and strategic hiccups along the way, JESSI is credited with closing a technology gap in the development of integrated circuits that was opening between Europe and its competitors in the United States, Asian and Japan in the late 1980s (Blau and Wolff, 1997). The JESSI program provides a good opportunity to let European IC companies to keep abreast of the advanced technology development in the world.

From the supply and demand structure of the European market during the past decade, total revenue generated by the top three European semiconductor companies: STMicroelectronics, Infineon and Philip together comprised over 70% of the total European market (DigitTimes, 2000). One of the cornerstones of Europe’s increasing success in semiconductor is the match between the needs of the industry and the fields in which R&D centers in Europe are working (Deferm, 2001). In Europe, collaboration between R&D center and R&D department of companies forms a base of cost sharing and SIP (Silicon Intellectual Property) creation whatever possible, thus strengthening the competitive advantage.

European countries, including: England, France, Holland, Italy and Germany lack the economic fundamentals to drive an effective semiconductor industry due to the dispersed technology research and small market scale. The IC industry is a capital and technology intensive industry. The development of the European IC industry has lagged by the unavailability of instant capital and updated technology comparing to the advanced IC technologies developed by US and Japan. The structure of the European IC industry changed in the 1990s because of rapid growth in the revenues of the dominant companies. This development created the pressure for merger and acquisition activity.

Joint ventures were established between European companies and Taiwan IC companies to co-invest in Taiwanese fabs, with notable examples being Philips and TSMC, and Infineon and Promos during the 1990s. Philips, the Taiwanese IC industry and government jointly invested TSMC, and its technology came from both Philips and ERSO (Electronic Research Service and Organization), which was a division of ITRI (Industrial Technology Research Institute). Meanwhile, Germany's Infineon entered the Taiwanese IC industry through strategic alliances with Taiwanese IC companies like Winbond and Promos following 2000, being motivated to do so by the increasing maturity of the Taiwanese IC industry. For the Taiwanese IC industry, the involvement of the top three European companies offers another opportunity to cooperate in the development and migration of their technologies. However, developing reciprocal agreements among these companies is difficult, partly because of cultural differences, business operation attitude and political or economic factors.

4. Asian IC industry

Japan and US no longer dominate the worldwide IC market since other countries in Asia, especially South Korea have substantial and powerful IC manufacturers since the 1990s. In just over a decade, Korean firms led by Samsung, Hyundai (known as Hynix after 2001) and Goldstar have become major players in the production of integrated circuits, particularly memory chips. They stared with meager resources and competitive disabilities – yet they have managed to turn these to their advantage in devising catch-up strategies that have brought them to the world's technological frontier (Mathews and Cho, 1999). Under the policy of government support and industry concentration, Korea has developed its IC industry successfully.

South Korea's IC industry had achieved strong progress in entering memory product production since 1983, and has become the third largest semiconductor supplier in the world. Semiconductor production value in South Korea increased from 6.5% of total global production value in 1994 to 21% in 1998. The growth rate of the South Korean semiconductor industry in 1999 was 46%, significantly exceeding the global semiconductor industry growth rate of 18%. Notably, memory products formed the core of the South Korean IC industry. The key precondition for successful entry through resources leverage into a high technology industry is availability of product and process technologies, such as licenses. This provided the key to South Koreans' strategy, Samsung purchased the 64Kb (Kilo-bits) DRAM (Dynamic Random Access Memory) designs from US firm Micron, Hyundai licensed 16Kb and 64K DRAM designs from Vitelic of California, USA and 64Kb SRAM (Statistic Random Access Memory) from MOS Electronics of USA, and Goldstar secured telecomm ICs designs from its US joint venture partner, AT&T, and technology transfer from Hitachi (Byun and Ahn, 1989). The rapid product turnover and the need for new process technology investments with each new generation of DRAM have provided the opportunity for new comers to create a market. What were once seen as a barrier to market entry thus has become a window of opportunity for latecomers. Japanese exploited this kind of characteristic of semiconductor industry, with their assault on the US DRAM market in the early 1980s. Furthermore, South Korea repeated the process in the 1990s, by engaging in the mid-1990s, from Taiwan, Singapore and Thailand—all capitalizing on the opportunities created by the restless product turnover in this sector, and the availability of dedicated equipment for fabrication (Mathews, 1995). It makes Korean IC memory makers to be the leaders in the world market in late 1990s.

The South Korean IC industry faces three major issues: excessive reliance on memory products, high dependency on imported equipment and raw materials and a lag in design technology. Process and manufacturing technologies, capacity and quality are the competitive advantage of South Korea compared to other countries. The structural drawback of excessive concentration on memory products makes the development of the South Korean IC industry highly dependent on economic cycles and imported equipment and materials, and moreover means that it lags severely in basic design technologies. The production ratio of memory and non-memory products is 80:20 in South Korea, compared to a global market scale ratio of 20:80 (DigiTimes, 2000). The memory based development strategy of South Korea thus faces constraints from the limited global demand for its products. Korean and Taiwanese IC companies have been fierce competitors since the 1970s, and no cooperation exists between the IC industries in the two countries. Success stories involving Korean IC companies formed a learning model for the Taiwanese IC industry and stimulated industry progress.

South-east Asian countries, including Singapore, Malaysia and the Philippines are focused on low-end testing and packaging, invested by U.S., Japanese and European companies. However, Singapore has a unique competitive edge owing to government support and planning, and CMS (Chartered Manufacturing Semiconductor) and STM (STMicroelectronics) were the two major wafer fabrication companies before 2000. World IDM (Integrated Device Manufacturer) companies like Philips, Infineon and AMD (Advanced Micro Device) cooperated with TSMC and UMC to establish new 12-inch wafer fabrication plants. For example, SSMC (System on Silicon Manufacturing Company) and UMCi (UMC and Infineon) in Singapore scheduled to be established before 2004. Singapore is vying for the same Silicon Island mantle as Taiwan, and its government is driving the development of a chip manufacturing environment. Singapore is capable of becoming a foundry center for the Asia/Pacific region in the future, and makes come to share this role with Taiwan.

Malaysia has attracted many foreign companies such as Intel, AMD, Motorola and Taiwan's ASE (Advanced Semiconductor Engineering) Inc. to establish] packaging and testing houses there since the 1970s. More recently however, two 8-inch wafer fabrication plants, namely: 1st Silicon and Silterra, debuted mass production around 2001, thus establishing the first primary capability of the Malaysian IC industry. Packing and testing houses invested by Intel, Philips, Cypress and Motorola dominate the semiconductor industry in Philippines, but no wafer fabrication plants have been established to date. Regarding East-South Asia countries, foreign companies invested based on little more than the advantage of low-cost labor, and thus they suffered significant losses following the Asia monetary crisis in 1997. These countries now face the challenge of differentiating themselves from China and establishing their own competitive advantages following the entry of China to the WTO (World Trade Organization), a development that has stimulated aggressive development of industrial parks and allowed China to further capitalize on its advantages of low cost and a huge market. These countries, with their poor infrastructure and industrial policy, face the risk of being marginalized as China develops its own IC industry. Cooperation between Taiwan and East-South Asian countries is likely to remain limited unless the competitive advantage of industrial development can be established.

5. Chinese IC industry

China developed its first IC in 1965, but the development of its IC industry seriously lagged other countries until 1990s (Lee, 1999). The development of the Chinese IC industry has been very slow under the surveillance of COCOM (Coordinating Committee for Export Control) in the past time. In 1994, China semiconductor product value was US$211 million, representing just 0.19% of the global semiconductor market of US$110.25 billion. There was a stable growth rate of around 36% in CAGR (Compound Annual Growth Rate) from 1994 to 1999. The structure of the Chinese IC industry has gradually shifted from IDM to vertical disintegration of design, manufacturing, testing and packaging following the implementation of the eighth and ninth five-year construction plans and from 1991 to 2000. Under the tenth five-year construction plan proposed in 2001, the Chinese government will put US$50 billion into IC industry development over the next 5 – 10 years helping to stimulate total investment in the industry of around US$150 billion (DigiTimes, 2000). Under this situation, the Chinese IC industry is expected to maintain double-digit growth in the future.

The major wafer fabrication plants in China are Tien-jin Motorola, Shougang-NEC, Shanghai ASMC (Advanced Semiconductor Manufacturing Company), Shanghai Belling, Wushi CSMC-Huajin, and so on. The scale of the Chinese IC market was US$2.38 billion in 1995 and increased to US$10.46 billion in 2001, while IC industry production value of was US$0.42 billion in 1995 and increased to US$1.18 billion in 2001 (IEK/ITRI, 2002). China has taken the advantage of its cheap and abundant labor to attract direct investment from multinationals, thus accelerating the pace of industrial development.

Taiwanese IC companies have established fabrication and assembly plants in China to exploit low labor costs and proximity to huge potential markets. However, the Taiwanese government has tried to limit the exodus of industry to China and limit the flow of technology across the strait to protect the local IC industry not becoming hollowlization. Inevitably though, the future trend will be for more offshore IC makers to establish fabs in China. China has promised to lift its mandate and further open its domestic market after entering the WTO. China is pouring billions of dollars into new infrastructure with the goal of becoming a leading IC industry supplier in the world. If the Taiwanese technology industry obtains much more benefit from investing in design houses, and manufacturing, testing and packaging plants in China, where labor-costs and other overheads are much cheaper than in Taiwan, then Taiwanese companies will increase their profits.

Massive IC technologies, management and engineering talent and capital have been pouring into China from Taiwan especially since 2000. The Chinese IC industry thus has entered a new era of development. Taiwanese manufacturers face critical choices, simultaneously facing pressure to enter China ahead of their competitors] and also having to consider Taiwanese government restrictions on Mainland Chinese investment. The Taiwanese industry is attracted by China by low labor and land costs, a huge potential market and the limitations of the Taiwanese investment environment. Investment in China by the Taiwanese IC industry is a very import variable for the vigorous development of the Chinese and Taiwanese IC industries. For the Taiwanese IC industry, establishing partnerships with China is one aspect of globalization and can help to diffuse and extend Taiwan’s strengths and global advantages.

The global IC industry developed initially from the 1960s, with the most intense development occurring in the US in the 1970s and Japan in the 1980s. The successful development of the Taiwanese IC industry in the 1990s changed this pattern of US and Japanese domination, creating a new era of competition and cooperation among the IC industries of different countries after 2000.

Development History of IC Industry in Taiwan

Industrial development in Taiwan

Every country and each industry has its unique development characteristics under the various environmental backgrounds. A review of the history of industrial development in Taiwan focuses on each decade (Tsai, 1999):

● In the 1950s, the government adopted the first import substitution policy. Industry development focused on labor-intensive and light import substitution industries.

● In the 1960s, the government adopted an export expansion policy. Overseas markets opened swiftly through the international comparative advantage of low-cost light industries.

● In the 1970s, the government adopted a second time import substitution and export expansion policy for heavy industry. Promoting the development of strategic oil and chemical industries, mechanical industries, and information and electronics industries. The labor-intensive consumed property was turned into a technology-intensive production property. The structure of industry changed substantially.

● In the 1980s, the government adopted a strategic industry policy. Ten new emerged industries (communication, information, consumer electronics, fine mechanical and automation, advanced material, semiconductor, special chemicals and medicine, aero navigation, medical health care and pollution prevention) and eight key technologies (optical electronics, software, material application, industrial automation, advanced sensor, energy saving, resources development and biotechnology) were recommended for industry to develop. Industry structural adjustment was underway through financial support, technology, management and marketing reformation.

● In the 1990s, the government adopted a policy of upgrading traditional industries and promoting ten items for high technology industries: communications, information, consumer electronics, semiconductors, precision mechanical tools and automation, aero-space, advanced materials, special chemistry and drugs, medical treatments and health care products, and pollution prevention as key industries for development. The government encouraged industry to step into these fields by granting subsidies.

Taiwan has become one of the four small dragons in Asia due to the industrial development policies conducted by the government in the past decades that created the famous economic miracle in Taiwan.

Developmental history of IC industry

In the 1960s and 1970s, Taiwanese IC industry was just beginning. All the assembly industry almost migrated from foreign companies like GI (General Instruments) Company and TI Company. This was a stage of labor-intensive and assembly-oriented industry. Most of the IC products produced in these periods were SSI (Small Scale IC), MSI (Medium Scale IC) or LSI (Large Scale IC). In the 1980s, the IC industry shifted from a labor-oriented industry into a technology-oriented industry. The industry structure was readjusted. IC design technology had changed from LSI to VLSI (Very Large Scale IC). Many IC design centers and fabrication plants were established to meet the rapid increases of market requirements. After entering into the 1990s, management of manufacturing, engineering and technology development had become the most important factor because the IC industry technology has shifted from VLSI to ULSI (Ultra Large Scale IC) that integrated more numbers of transistors circuit into a smaller chip area. Advanced and differential technology competition in R&D and manufacturing is more serious than before. Managing alliances, technologies integration and manufacturing upgrading were the key focus in the 1990s. For Taiwan, the IC industry has a special meaning in its industrial development history through technology evolution. The dynamic technology formation of the Taiwanese IC industry from the 1970s to the 1990s can be shown as in Figure 2. As for the year after 2000, it will step into another silicon cycle (for example: 12” wafer) that the transformation will be reformulated under the vicissitudes of technology evolution.

Starting from transistors and IC assembly with technology transferred from the USA, the Taiwanese IC industry has developed product design from SSI, MSL to LSI, VLSI and ULSI, and wafer fabrication from 4-inch to 6- inch, 8-inch and 12-inch. UMC, TSMC and VISC (Vanguard International Semiconductor Corporation) firstly started their 4-inch, 6-inch and 8-inch wafer fabrication technology in 1980, 1987 and 1994 respectively. Furthermore, TSMC had started its 12-inch wafer fabrication technology in 2001. Wafer fabrication has a positive correlation with the technology advancement in IC industry. Larger wafer size indicates the increased numbers of IC chips included usually around 1.8-2.2 times from each generation of 4-inch to 12-inch with the same chip area. As viewing of the

21 years from 1980 to 2001, there are four generations of wafer fabrication technologies that every seven years had a new technology deployment from 4-inch, 6-inch, and 8-inch to 12-inch. It was found that the silicon technology cycle of IC industry in Taiwan was seven years rather than the conventional rule of four years in this industry around the world. This evolution has reveled that the technology formation is processed from step-by-step through the involvement of government, research institute, foreign IC related leading companies and over 500 private companies in this industry.

Development stages of IC industry

There are many descriptive categories for the developmental stages in the IC industry from literatures review. In the first " 1991-Yearly Book of Semiconductor Industry" published by ERSO/ ITRI, the developmental period for the IC industry was categorized into the following three stages (ERSO/ITRI, 1991):

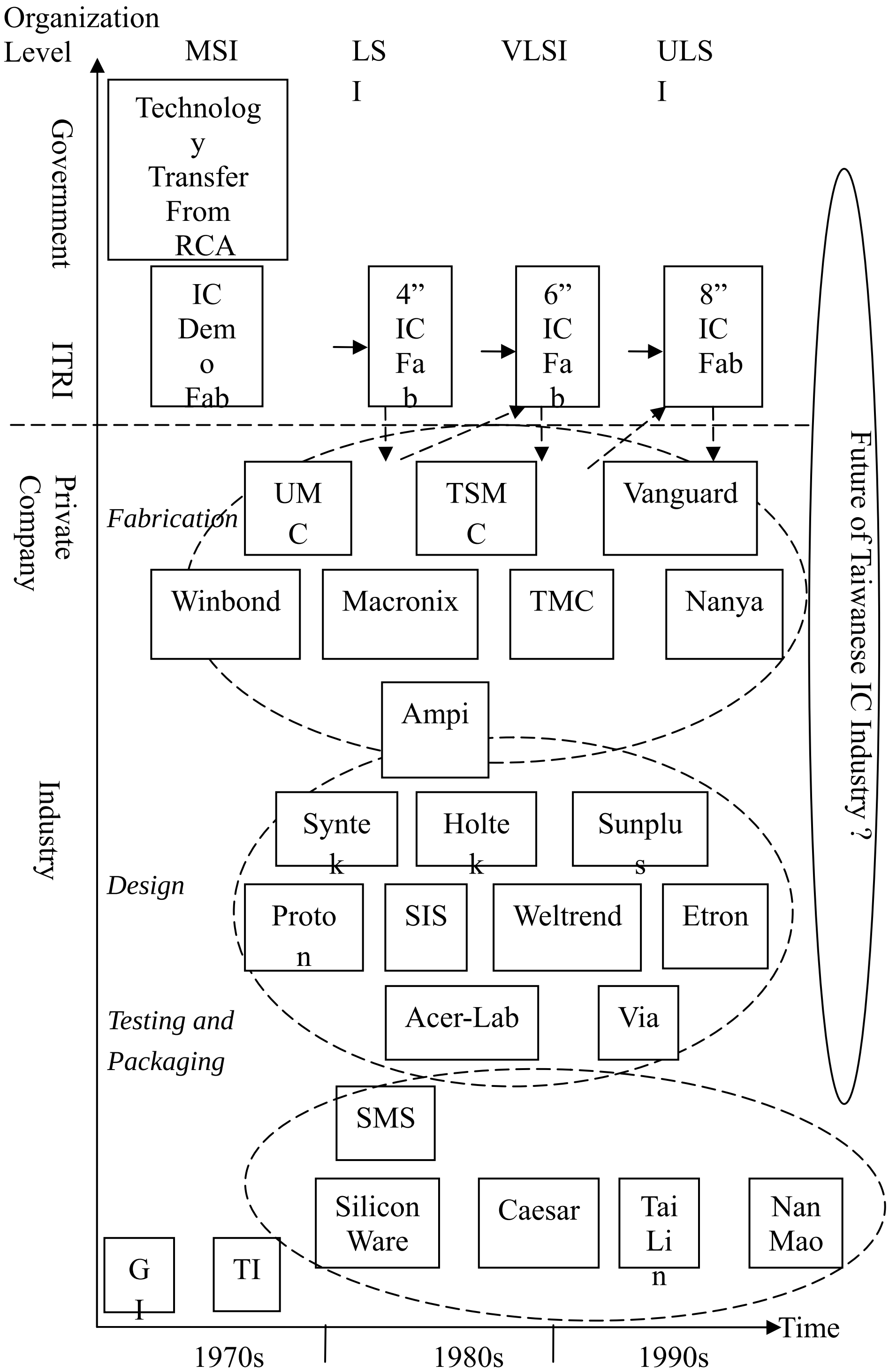
● Burgeoning stage (1964-1976)

●Technology transfer stage (1975-1979)

●Technology self-reliance and diffusion (1980s)

Figure 2

Dynamic Technology Formation of Taiwanese IC Industry



MSI: Medium Scale IC
LSI: Large Scale IC
VLSI: Very Large Scale IC
ULSI: Ultra Large Scale IC

According to the description by ITRI in its "20 years review of ITRI" publication, four stages were described for the government's IC technology implementation in ERSO/ITRI from 1975 to 1992 (ITRI, 1993):

● Technology transferred from foreign companies
● Technology localization and diffusion
● Industrial growth
● Industrial boom

One researcher had found that the development of Taiwan's IC industry could be categorized into five distinct stages (Lee and Pecht, 1997) :

● Embryonic period (1966 – 1976)
● Technology acquisition (1976 – 1979)
● Technology creation and diffusion (1979 – 1983)
● Growth stage (1983 – 1988)
● Government-private technological collaboration (1990 – 1995)

Another one researcher had analyzed the Taiwanese IC industry development process and classified it into three stages (Chang and Hsu, 1998):

● Initiation stage: consisting of obtaining technology and facilitating the establishment of domestics companies
● Burgeoning stage: consisting the formation of manufacturing R&D ability.
● Growth stage: consisting of raising the industry's international competitive level.

The other one researcher had analyzed the growth of the Taiwanese IC industry and divided it into six phases (Hsu and Chen, 1999):

● Phase I - Industrial hoarding (1960-1980)
● Phase II - Industrial burgeoning (1981-1983)
● Phase III - Fast growing (1984-1988)
● Phase IX – Industry 1st transition (1989-1992)
● Phase X - Stable and re-growing (1993-1996)
● Phase XI - Industrial 2nd transition (1997 onwards)

The above-categories for the IC development stages had tracked the industry history. In contrast, these kinds of categories do not cover the period up to the year of 2000 and also are not viewed from the uniqueness of industry itself. A new categorization is studied and recommended that full of history, evolution and technology that based on the managerial peculiarities of the development in this industry.

The development of the Taiwanese IC industry can be categorized into three stages by technology management perspective: labor-intensive stage in the 1960s and 1970s, technology- intensive stage in the 1980s and capital-intensive stage in the 1990s. There are three reasons for this category: First, it matches with the technology developmental path from assembly to manufacturing and design technology, and capital investment. Second, there was intensive technology development in manufacturing, design, packaging and testing houses in the 1980s due to the matured production technologies from 4-inch, 6-inch and 8-inch wafer that dominated the industry from the 1970s to the 1990s. Third, leaders of the IC industry in Taiwan were capable of developing their own design and fabrication technologies in the 1990s that launched out the new era of investment on the co-development technology program outside of Taiwan beginning from the end of 1990s.

Exploratory Formation of Labor-Intensive Stage

Strategic inflection points

The development process of evolution was full of strategic transformation. There are three strategic inflection points in the development of a high technology industry. A strategic inflection point is the giving away of one type of industry dynamics to another. Strategic dissonance exists when there is a growing divergence between what the industry puts forth as its strategy and the particular actions taken. Strategic dissonance often signals that the industry has reached a strategic inflection point in its development that is a major crossroad for the industry (Burgelman and Grove, 1996). Strategic dissonance requires strategic recognition that is the responsibility and capacity of top management to appreciate the strategic importance of managerial initiatives after initiatives have been launched but before definitive environmental feedback is available. The role for top management is to recognize the gap between strategy and actions, explore the possibility that this may be a strategic inflection point, and examine openly how the gap can be eliminated by defining a new strategic intent (Hutt and Speh, 1998). The strategic inflection point provides an excellent opportunity to industry for transformation.

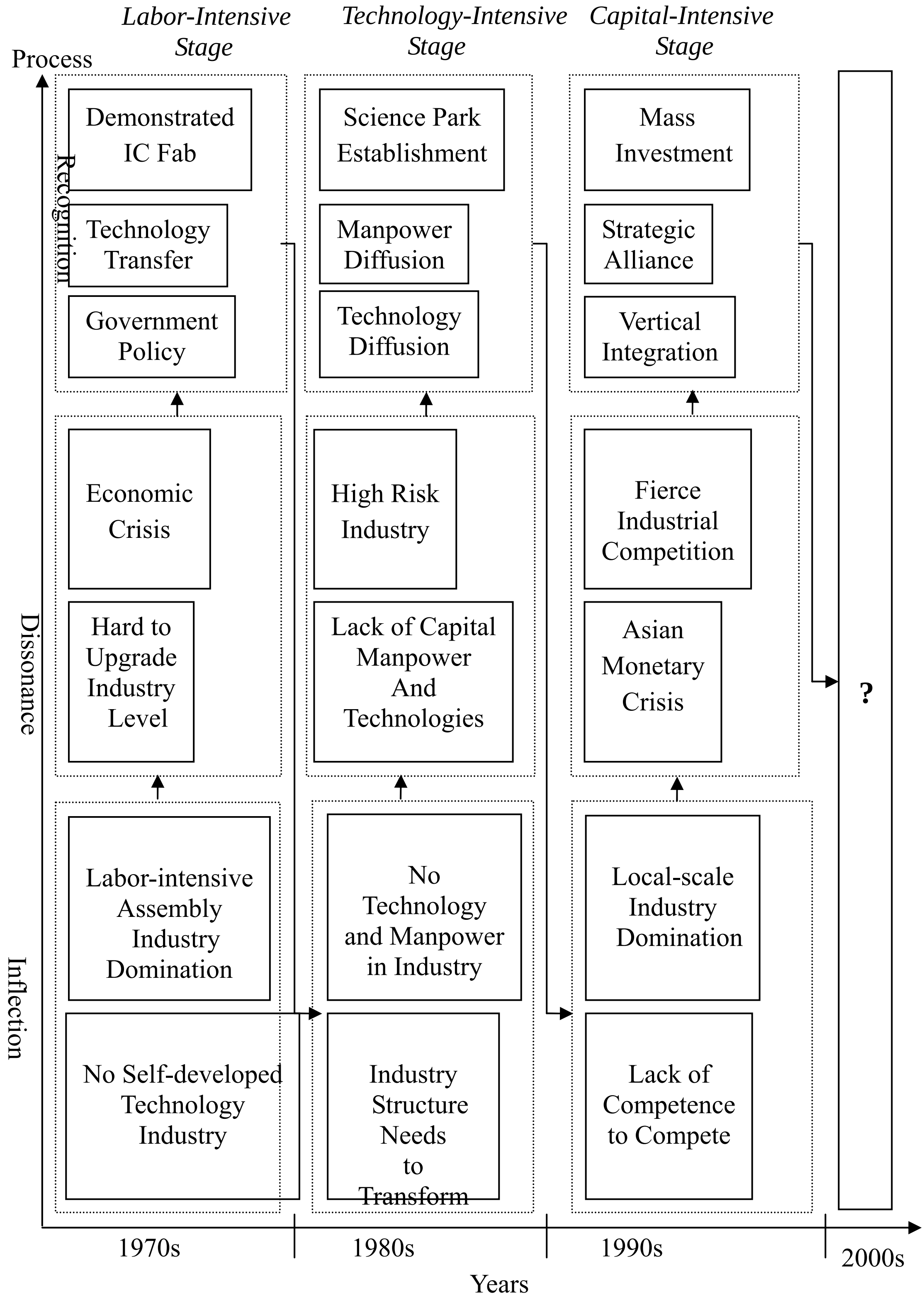
Taiwan's significant economic growth and rapid movement into the IC high technology sectors is viewed as the best chance for Taiwan becoming a major IC industry player in the world. Within this development, the transformation from labor-intensive, to technology-intensive and capital-intensive stages was considered as critical processes in sustaining Taiwan's industry development strategy. The strategic transformation process of the Taiwanese IC industry by year and the related three strategic points are shown in Figure 3.

IC technology acquisition

In the early of the 1960s, Taiwan was a labor-intensive country and most of its national income came from the textile industry. Conception of electronic industry development burgeoned in the early of 1960s after the first national "Modern Engineering Technology Forum" was held in 1966 (Wu, 1999). This forum called for many of talent Chinese-American scholars and experts to present modern technology

Figure 3

Strategic Transformation Process of Taiwanese IC Industry



development in the world and suggested Taiwan to develop the electronic industry for elevating the economic level and courting the publicity of country. Taiwan had no self-developed technology due to lack of R&D investment before the economic crisis in 1974. Many of foreign Chinese experts proposed a developing program for Taiwan to upgrade its technology level through TAC (Technical Adviser Council) recommendations of ITRI. At that time, the chief of the Executive Yuan, Chiang Ching-kuo had recognized that Taiwan must have a big breakthrough in industry to survive and keep abreast of the times.

The establishment of the industrial technology was conducted by the MOEA (Ministry of Economic Affairs) after evaluation. Technology transfer was the best and fast way to level up the country's technology. This project finally attracted three American companies to run after: GI, Hughes and RCA. MOEA chose the RCA company at last on account of three agreements: (1) RCA agreed to train design and fabrication people and update the transferred technology contingent upon the evolution of technology. (2) RCA possessed factory land in Taiwan and had full. (3) RCA agreed to buy back products fabricated in Taiwan. The technology transfer contract with the RCA Company was signed in March 1976. Consequently, the first demonstrated pilot fabrication plant was set up with a capacity of 3-inch 4,000 wafers per week in 1978 (Su, 1994). This is a significant step to start for the Taiwanese IC industry.

Technology transfer

In 1974, a statement was made that Taiwan should skip the transistor assembly stage and stepped directly into IC development. This was a critical inflection point in Taiwan IC industry development. The government had strategically built the infrastructure and putting its effort into the technology transfers from RCA Company to set up Taiwanese owned IC technology. People were trained at RCA to gain advanced technology knowledge according to the agreement. This was the key, swift and effective way to establish an IC industry in Taiwan.

Early in the 1960s, the first semiconductor laboratory was established at National Chiao Tung University under the support of the United Nation's Fund. This project was only for educational laboratory purposes. Some of the basic research in IC technology and been studied. In 1975, MOEA commissioned ERSO to develop key components. The first commercial IC technology: CMOS process technology with 7-micron meter design rule was transferred from RCA Corporation, USA into

ERSO / ITRI in 1976. ITRI is a government supported non- profit organization that dedicates in research and development for electronics, materials, mechanical and chemistry etc. Based on the transferred technology from RCA, ERSO's engineers improved and updated this technology. This program had proven itself a great success and implied that Taiwan had capability of mass- producing its own IC products.

In this phase, MOEA successfully implemented the government project through ERSO/ITRI: Phase I Electronic Industry Development Plan from 1975 to 1979. During the labor-intensive stage, Taiwan had prepared to shift itself from the assembly industry into the technology industry, setting a good milestone for further development.

Strategic Transition of Technology-Intensive Stage

Disparity of technology capability

There was a rapid growth in the Taiwanese IC industry during the 1980s. The technology resources were generously diffused from ERSO/ITRI to industry by way of spin-off teams. After the government and research institute incubated the first IC private company – UMC in 1980, the IC industry soon found that it was difficult to expand its business due to the lack of experienced technology and management talent. This kind of people was difficult to find in the local market especially for a wafer fabrication operation. It was hard to invite the sufficient experienced Chinese-American experts and engineers coming back to Taiwan to support the IC industry in time.

Technology and manpower diffusion

The world famous Hsinchu Science-Based Industrial Park was established in 1980. It offered a one-stop solution for the new start-up high technology companies. The first full-fledged spin-off IC company: UMC enlightened the era of first-commercial IC manufacturing company, starting with 3-micron meter IC design rule and 4-inch wafer fabrication in Hsinchu Science-Based Industrial Park, 80km southern away from Taipei, Taiwan (IERC/ITRI, 1987). The first private IC design house – Syntek Company was established in 1982. UMC and Syntek companies gave many investors the strong confidence to step into the high-technology industry.

Many of design houses such as: Holtek, SIS, Realtek, Mosel, Sunplus, Weltrend were set up successively in 1983, 1987 and 1989. Taiwan's first private 6-inch wafer fabrication and the world's first pure IC foundry company – TSMC was founded in 1987. As one of the major IC technology, lithography of IC manufacturing is used to copy the fine electronic circuit diagram onto a silicon wafer, layer by layer, after the photomask is completed. A private photomask service company – TMC (Taiwan Mask Corporation) spun-off from ERSO and was set up in 1988. Wafer fabrication plants like: Winbond, Hualong Micro-electronics, and Macronix were set up one by one during 1987 and 1989 after TSMC was established. The movement and operation of these companies dramatically influenced the economic and industrial cycles of entire IC industry due to their large markets share. All of the wafer foundry companies were IDM before TSMC arrived. IDM companies performed not only wafer foundry operations but also had owned brand IC products. There was quite a difference between foundry-only and IDM companies. Foundry-only companies do not produce their owned brand IC products. It is impossible to compete with the foundry's customers and that indirectly has protected the intellectual property rights of its customers. Each company positioned its business operation contingent upon an individual corporate strategy no matter what for IDM or foundry-only chipmakers. In the late 1990s, UMC and TSMC are able to co-develop the advanced technology (for example: deep sub-micron technology) with the world's IC industry leaders like Intel and IBM companies.

IC industry is a highly risky but high profit industry. Investors concerned about the technology sources and talented manpower for success. One way was to diffuse the technology and management manpower from research institute liked ERSO/ITRI in a steady stream continuously. Then the diffused talent in private sector will rediffuse the next generation's manpowers to the other new private sectors in the industry that new private sectors within the industry that composed of the diffusion paradigm of ERSO/ITRI family. This is a very special and important family culture that underlying the development of IC industry to steer a steady course and particularly distinctive to the other industry development in 1980s and 1990s.

The diffusion of technology and experienced manpower from ERSO/ ITRI and spin-off companies provided a very good foundation and springboard for industrial development in IC industry. People who came from ERSO scattered around the design houses, fabrication plants and packaging/testing houses. Many of them being industrial elites and leaders were not only characterizing the same culture and behavior style but also shaping out the unique industry and corporate culture. The ERSO family had performed a well networking of human connections with special consensus. Human relationship networking has special importance in covering the transaction cost, information costs and information communications (Wu, 1999). Family relationship networking played a different role in each development stage in the IC industry development in Taiwan.

Contributions of Science-Based Industrial Park

Hsinchu Science-Based Industrial Park, National Chiao Tung University and National Ching Hua University, nearby ITRI were a magnets and helpers in providing a satisfactory environment for the development of high technology under the planning and control of the government's Science Park Administration Bureau, National Science Committee, Executive Yuan in the 1980s and onwards. This situation provided a very important momentum for the development of IC industry. Because it provided at least two major benefits for companies in the Science Park as compared to non-Science Park companies: (1) 5 years tax-exemption (2) Sound infrastructure for living, learning, school, factory house and working environment. The government encouraged the construction of many industrial parks, incubator centers, information services and developments in order to set up an effective infrastructure of information highway for the IC industry in Taiwan. During 1980s and 1990s, the park became the base for the high technology industry not only for foreign firms but also for a numerous overseas Chinese start-ups and homegrown companies. Furthermore, the total investments came from government reached to US$1.8 billion that induced the accumulated investment amounted to US$21.7 billion in 1980s. In other words, it indicated the government's one-dollar input had attracted industry's twelve dollars in investment. The total revenues of industry in Hsinchu Science-based Industrial Park was US$29 billion that shared 10% of national manufacturing industry value and 30% of national electronic and information industry values of Taiwan in 2000 (Science Park Administration, 2000). This weighting is increased years by years that indicate the important degree of IC industry dependency in Taiwan.

In this phase, MOEA successfully completed a government project through ERSO/ITRI: VLSI Technology Development Plan from 1984 to 1988. The purpose of this project was to set up an IC common design center in ERSO and to establish VLSI laboratories. This project spurred the establishment of over 40 IC design houses in Taiwan in the 1980s. The engineers who worked with VLSI laboratory were the original teams for TSMC (ITRI, 1993). The IC common design center originated from the concept of common CAD tools for smaller scale IC design houses and non-IC design companies under the requirements of designing their own IC products by themselves. The implementation of an IC common design center had created much opportunity for interested groups to set up their own IC design houses afterwards.

Inspiration for Capital-Intensive Stage

Developing barrier to industry development

In the beginning of the 1990s, the basic IC technologies were set up successively due to the trend of technology- intensive domination. The IC design and process capability still stayed at low level comparing to the foreign leaders. Taiwan IC industry lacked of the core competence to take a competitive advantage in the world market. It was necessary to develop the advanced technologies and high-end products to enter into the world market. Taiwan was unable to keep abreast with the leading foreign companies in the IC industry without foreign resources. In 1997, the Asian monetary crisis occurred which let Taiwanese IC industry fully recognized the importance of searching strategic alliances with foreign leaders, and vertical integration of sub-industries to obtain the substantial synergy benefits for competing in the world market.

In search of strategic partners

Electronic and Information markets were booming around the world in the 1990s. Taiwan had found that it was difficult to compete within this industry without core competence. A strategic alliance was needed to keep abreast of state-of-art technology and supersede outmoded technology. Many of companies had searched for strategic partners from USA and Japan sourcing their advanced technologies.

Taiwanese IC industry was incapable of developing its own technology partly because of the fast and dynamic changes in technology advancement. The best and quickest way was to build up the strategic alliances with leading foreign companies to procure the advanced high technology. No longer to confine the policy of self-development in technology, nearly all of the Taiwanese IC companies have strategic partners over the design houses, manufacturers and packaging/testing houses in 1990s. Strategic alliance plays a key role in upgrading the capability of the IC industry in Taiwan. According to the theory of power dependency and transaction cost, the performance of alliance exists positive correlation with the conditions of membership (Olk and Young, 1997). A three-cornered alliance between Winbond, Toshiba and Fujitsu; cooperative arrangements between ProMos, Mosel Vitelic and Siemen's spin-off Infineon: another three- cornered arrangement between Powerchip, Vanguard and Mitsubishi; and cooperation between Nan-Ya and IBM are examples.

In the mid-1990s, vertical integration played another key factor in the development of the IC industry in Taiwan. Due to the industrial clustering effects, which linked a whole slew of segmented industries together. Each company would focus on its best added value activities and emphasized on core competencies to build up a competitive advantage. Integration of Silicon Valley, USA for design, Hsinchu Science-Based Industry Park, Taiwan for manufacturing, and USA/Japan for equipment supply would form a strong golden triangle for the world's IC industry. Nevertheless, this situation will be changed owing to the emergence of Mainland China. China shared part of the IC market since the late of 1990s. Well-developed business networks and strategic cooperation will enforce the trend of vertical integration (Ma, 1999). All of Taiwanese IC foundry house recognize that fabrication is still the most profitable business and provide more investment in this field. However, this situation had biased the resources distribution of the industrial development from the national viewpoint. Unbalance industrial development will heavily impact the natural development of entire national growth.

New wave of capital investment

In the IC industry, relatively large infusions of capital must be periodically bestowed on equipment and research, with each infusion exponentially larger than the one before. Moreover, it is true for any company, investment in research; new equipment and the like must eventually generate a healthy profit (Hutcheson and Hutcheson, 1997). Although the impact of the Asian monetary crisis in 1997 caused the IC industry to become more deliberate in investment. A 10-year investment of around US$80 billion announced by 15 Taiwan IC companies in 1997 gave a big shock to the world. Taiwan's companies have strong confidence to enter into the world market through well-organized vertical integration and strategic alliance. There is three factors that making this possible: (1) Taiwanese IC technology, especially in production engineering management, has gained positive recognition from the industry leaders in the world. (2) The Taiwanese IC industry, originally backed up by the government, went its own way and self-developed strongly. Some of these companies are capable of forming alliances with the leading technology companies in the world. (3) The success of the IC industry has sparked interest largely for the traditional industries in Taiwan that trying to transform they into high technology industries.

In the 1990s, the sound infrastructure and environment attracted over 300 companies to get into the IC industry. Taiwan's first DRAM manufacturer – TI-Acer Corporation that transferred the technology from TI, USA was set up in 1990. Another DRAM maker – Power Chip Semiconductor Company that transferred technology from Mitsubishi, Japan was established in 1994. Memory and chip-sets design houses like: Mosel-Vitelic, Etron, VIA were established in 1991 and 1992 successively. Taiwan's IC industry became the 4th largest manufacturing country in the world in 1999. Taiwan's foundry business shared over 50% of the world market starting from 1997. TSMC and UMC ranked number 1 and 2 in the world market in foundry-only business. The product value of the Masked ROM (Read only memory), foundry industry, packaging /testing industry ranked number 1 in the world market on 1999. The number of IC design houses in Taiwan was about 127 in 1999 ranking as the second largest one after USA in the world. More capital flowed into the IC design sub-industry because IC products were widely applicable in 3C (Computer, Communication and Consumer) industries, especially in PC (Personal Computer) peripherals. According to the government's ITIS (Industrial Technology Information Service) project data, the sub-industry value of IC design house was amounted to US$715 million in 1995 and dramatically increased to US$3.3 billion in 2000 (ITRI, 2001). It implies the key policy and focus strategy of design sub-industry in the further development of Taiwanese IC industry.

A further step in the development of the Taiwanese IC industry was to spin-off the sub-micron meter IC technology team to set up the first private 8- inch wafer fabrication company- VISC with 0.35-micron meter process technology in 1994. This is an achievement in the implementation of the government's "Five-year Plan for Submicron Process Technology Development" starting from 1990 to 1994 (ITRI, 1994). Four ERSO's spin-off companies: UMC, TSMC, TMC and VISC created the IC products value amounted from US$2 billion in 1995 (ITRI, 1995) to US$8.3 billion in 2000 (ITRI, 2001). Introduction of VISC induced a wave of massive investment in the semiconductor industry for Taiwan. As a newly developed industrial country, Taiwanese IC industry has much confidence and optimism for the outlook of world IC industry in the years ahead no matter what the Asian monetary crisis occurred in 1997.

In this phase, MOEA had successfully completed the a government project "Five-year Submicron Technology Development Plan" from 1990 to 1995 by the expense of US$2.2 billion and with products vehicles of 16Mega DRAM and 4Mega SRAM (Static Random Access Memory). In 1995, MOEA had started another five-year's "Technology Development Plan of Deep-submicron Process" from 1995 to 2000 pushing the establishment of advanced semiconductor R&D center that driven by industry itself in the years after 2000.

Current Status of the Taiwanese IC Industry

There were many achievements made by Taiwanese IC industry over the past 30 years. It had found that the successful development of the Taiwan IC industry had constituted a sound foundation by way of dynamic networking among governmental policy, university cooperation, industrial development and foreign leaders' alliances.

Government policy

The government figured prominently being a dominant in the labor-intensive stage of high-technology industry. The government played a positive economic role by helping firms overcome social and political barriers in negotiations and technological communications (Watkins, 1991: Boulton, Dowling and Lohmeyer, 1992). The government frequently shared in the cost of collaborative R&D by subsides, expecting that the social returns would exceed the private return. In recent years, policymakers have added a new element to this familiar justification: helping domestic companies to generate and exploit technical knowledge to improve international competitiveness (Alic, 1990). Taiwan's government was a helpful propeller in the development of IC industry.

Taiwan government officials had far-sighted vision and had made a firm decision to start up the IC industry in the 1970s even though the 1974 oil crisis occurred worldwide. Under the guidance of National Science Committee, government put much effort to nurture and grow the infrastructure of Hsinchu Science-Based Industrial Park that attracted over 300 companies and 100,000 people to join up this park within 20 years. Networking on vertical integration and strategic alliance had created a unique and invulnerable competitive edge. All IC operation from circuit design to manufacturing, testing and packaging can be completed within the Science Park. This kind of vertical integration offering an absolute competitive advantage compared to other foreign companies. However, the corporate technology making is driven by the desire to develop economically successful technologies according to plan that government influences in that process is limited (Crow and Nath, 1992). Most of IC companies in Taiwan are reluctant to the government interferences due to its policy can not keep abreast with the market and environment change that forced companies to rapidly change its corporate strategy especially after years of 2000.

Furthermore, the infrastructure included: electrical power, water and land usually do not meet the speedy development requirements of industry after mid-1990s. Industry development does not occur with same speed in all districts, however the establishment of infrastructure plays a very important role in economic development as well as land procurement and approval of bureaucratic procedures (Rietveld et al., 1994). Electrical power outages sometimes occurred in the Hsinchu Science-based Industrial Park and lacked of water usually occurred in Tainan Science-based Industrial Park, 300km southern of Taipei where planned as the second model of Hsinchu Science-based Industrial Park. Governmental assistance was critical in securing stable power, water and environments for the smooth operation of Science Parks. The IC industry is still facing many challenges need to be addressed in order to maintain the further progress that had been the hallmark of

Taiwanese industries.

University's cooperation

Most of the R&D projects in the IC industry rely on two universities and one research institute: National Chiao Tung University and National Ching Hua University and ITRI because of favorable geographical position. All of these organizations are located in Hsinchu nearby the Science Park that offered superior backup to the development of IC industry. They provided a good source of trained technical people and technology procurement. Taiwan's IC companies focus mostly on the development of product technology and put little effort on the basic research. Research institute (for example: ITRI) had made its best endeavors to undertake the projects of technology research by way of co-development and/or consignment from industry. The most successful example was the IC industry that developed almost from zero to the top 3 IC production countries in the world within 30 years. Although the cooperation between university, research institute and industry is successful in Taiwan in the past, there are some weaknesses that can be improved in the years ahead:

-Mismatch in faculty research interests and industry needs;

-Lack of a market-driven mindset among faculty and academic administrators in dealing with resources allocation;

-Lack of proper university accounting and overhead structure to reflect a technology development foundation in a knowledge- based economic society.

Taiwanese IC industry has found a way to outsource key technologies from foreign leading companies, universities or research institutes that composed part of a global research and development system. For the shake of Taiwanese IC Industry is capable of developing their own technology, universities should play the role of studying the leading basic research for the advanced development of technology.

Industrial development

Particularly, IC industry development in Taiwan was partly triggered by the function of vertical integration especially in 1990s. Vertical integration is constructed under a sound infrastructure and industry networking of upstream and downstream sub-industries. Vertical integration occurs in the coordination of different industry stages when transactions in the industry chain do not benefit the industry members as a whole (Stuckey and White, 1993). Horizontal integration is good for economy of scope based on the acquisition of basic technology (Tassey, 1990). Vertical integration offered a sustainable competitive advantage that resulted form the possession of relevant capability differentials. The feedstock for these capability differentials is intangible resources, which range from patents and licenses, to reputation and expertise (Hall, 1992). The competitive advantage of technology comes from two factors: market advantage (including product differentials and add-on values) and cost advantage (Fleming, 1991). Market advantage requires the support of unique core competence. Core competence management in high technology must be based on a systematic and integrative framework that considers the status of the external environment and adjusts the internal environment through value- delivered processes (Knott, Pearson and Tayler, 1996). The Taiwanese IC industry has mastered its own core competence and value-added advantages over the technology- intensive stage. The vertical integration has been constructively and efficiently expedited through long-term repeatively trnasaction relationship between sub-industries.

The smart and working hard mind of Taiwan's engineers is a strong driving force for the IC development in Taiwan. The good performance of employee was triggered mostly from the company's incentive program. UMC, the first private IC Company in Taiwan, introduced the first profit sharing stock ownership program in 1985. All of the employees are shareholders in the company and can share earnings by stocks only if the company's business had profited on a yearling basis rather than the stock option adopted by US or European companies. Furthermore, some of key employee shared the unpaid stock option that made them feasible to become the millionaires in a short time. Today, hardly any IC companies do not follow this kind of program. This is the strongest driving force in the development and progress of IC industry in Taiwan.

One of the most critical successful factors derived from the development of the IC industry is the incentive program provided by the government. There are at least three official programs subsidizing industry to develop R&D projects: (1) To assist industry in developing new products program, conducted by Industrial Development Bureau, MOEA; (2) To assist industry in implementing government's program of technology development, conducted by Technology Division, MOEA; (3) To assist the companies of Science-based Park in developing key components, conducted by the National Science Committee. There are over US$120 million was granted by the government to implement theses programs in industry R&D on 1999. This is a great and effective measure to upgrade the technology of industry.

As reviewing the historical development of the IC industry, networking between the government and industry was another critical successful factor in developing this emerging high technology industry over the past 30 years. A special regional area around ITRI and the universities near the Science Park played a pioneering role. ITRI, universities and industry formed a golden triangle to construct a technology development platform as shown in Figure 4.

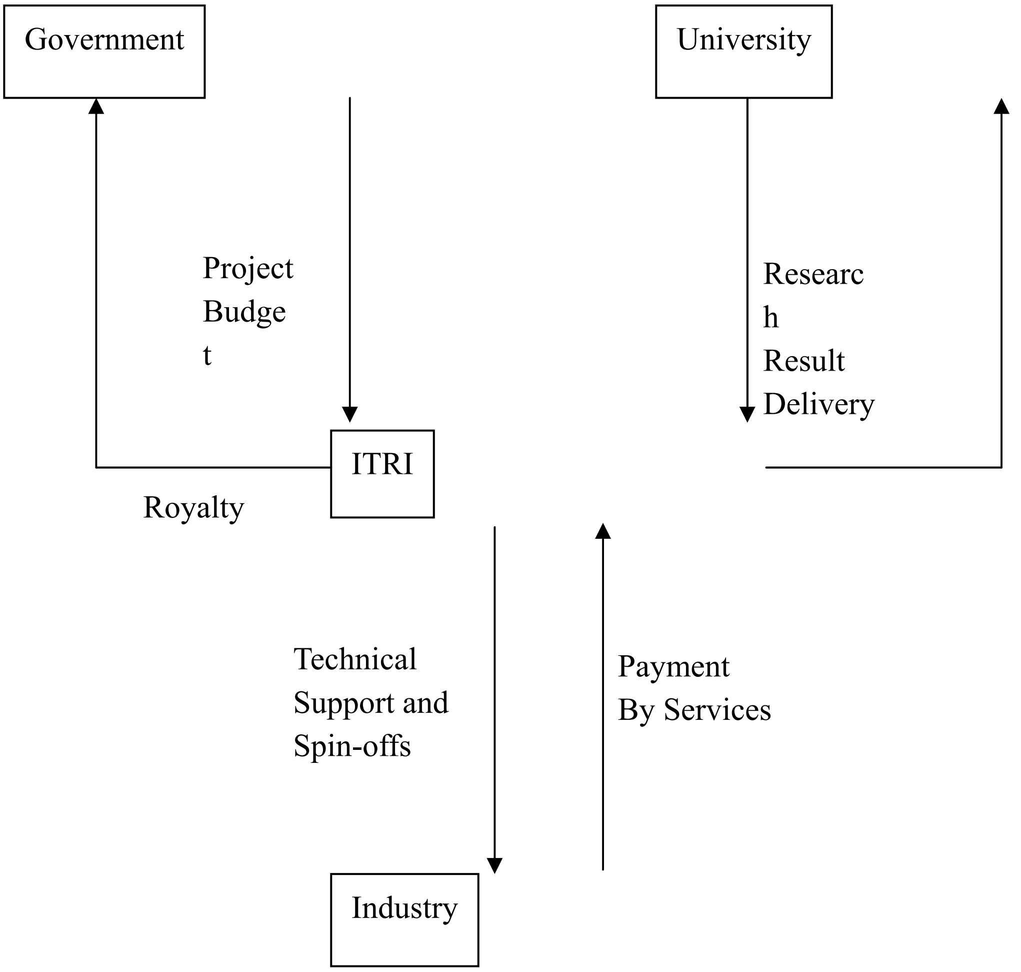
Foreign leaders' alliance

Taiwanese IC companies had put much money into R&D and to co-develop products with the leading companies in the world to foster their capability in 1990s. The traditional industry analysis approach focus on the important of industry structure and market positioning of organization (Porter, 1990). The newly emerged resource based viewings to a firm's unique resources, core competence, and dynamic capabilities in a rapidly changing global market (Barney, 1986; Prahalad and Hamel, 1990). Increasingly, vendors are taking ownership of IPR (Intellectual Property Right) that were strictly the company's bailiwick, and the Taiwanese IC industry is capable of allying with the famous IC companies that own the original IP products in the world. The acquisition of technology by alliance or merger and acquisition is considered difficult and rarely necessary. Strategic technology alliance activities remained at a rather modest level in the 1970s but grew to a phenomenal level in the 1980s and 1990s (Duysters, Gerard and Maaike, 1999). The purpose of a strategic alliance is mainly for business expansion, creating new opportunity and compensating for incapable technology (Heide, 1994; Doz and Hamel, 1998). Strategic alliances, a manifestation of inter-organizational cooperative strategies, entails the pooling of specific resources and skills by the cooperating organizations in order to achieve common goals, as well as goals specific to the individual partners (Varadarajan and Cunningham, 1995). The alliances wielded formidable influence in the process of technology development.

Most of Taiwan chipmakers not only build up strong technology team but also search for strategic alliance with leading global companies to robust their core competence. Examples are: TSMC with Philips and AMD; UMC with Cirrus, Lattice, Xilinx; Mosel with Siemens; Powerchip with Mistubishu, Winbond with Toshiba;

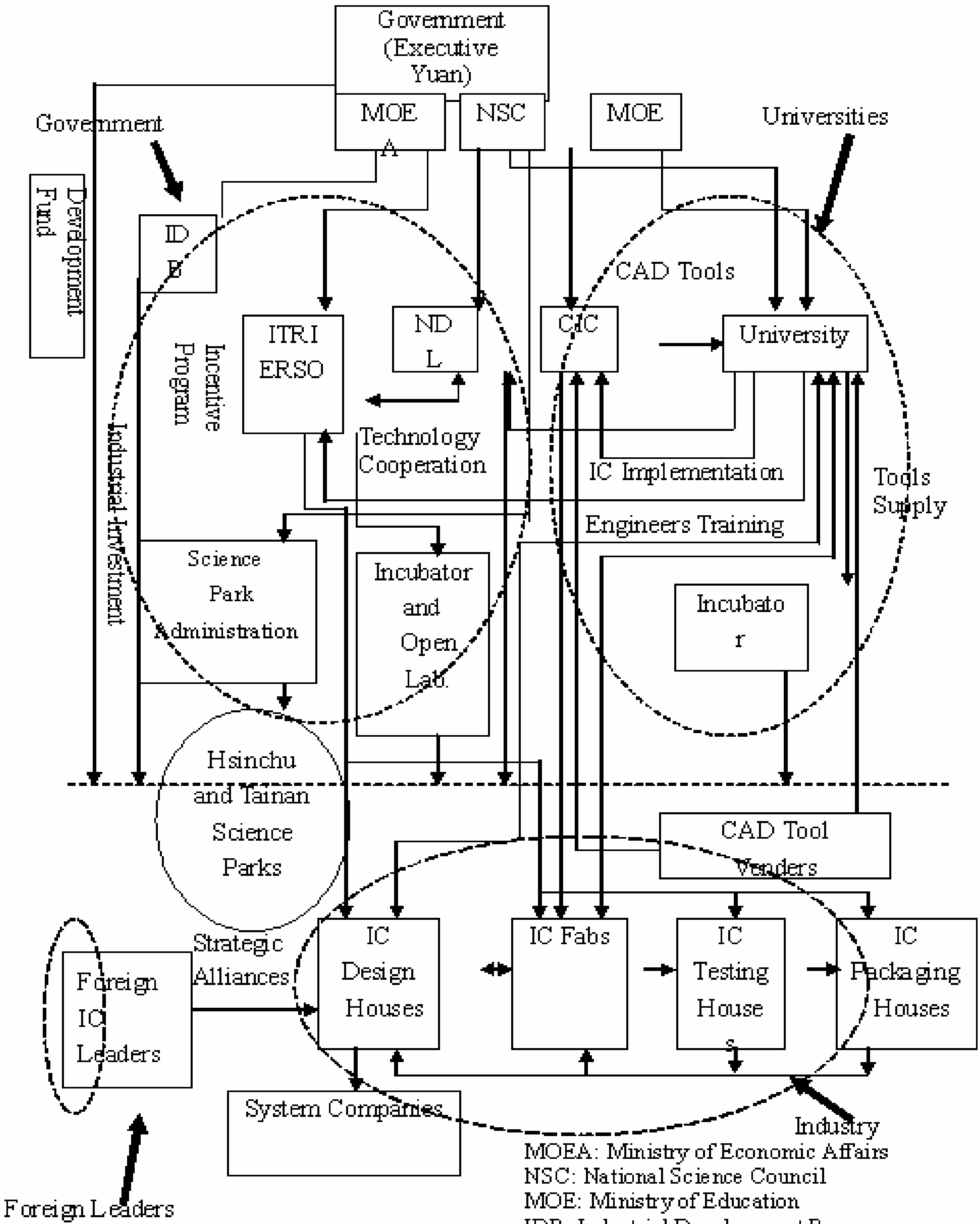
Figure 4

ITRI's Role in the Technology Development



Macronix with Matsushita; Nan Ya with OKI and IBM. The strategic alliances and vertical integration are the most important factors to form the competitive advantage for IC industry in Taiwan. The closed linkage among government organizations, industry and foreign leaders was shown in Figure 5. However, this situation will be changed because many of IC sub-industries such as: design, testing and packaging companies are moving out to Mainland China due to its low cost and huge market size in the late 1990s and beyond 2000. China has aggressively developed its own wafer fabrication plants since 2000 under the assistance of American, Japanese and Taiwanese counterpartners. Clustering effect will occur again in China in the 21st century. China regional and integrated **i**ndustrial development is a new reality that will inevitably lead to self- marginalization if Taiwan ignores this fact and adopt the policies to counter it. The structure of Taiwanese IC industry should be remodeled and readjusted in its own way.

Figure 5
Dynamic Networking Among Government, University, Industry and Foreign Leaders



MOEA: Ministry of Economic Affairs
NSC: National Science Council
MOE: Ministry of Education
IDB: Industrial Development Bureau
NDL: Nanometer Development Laboratories
CIC: Chip Implementation Center

Conclusion

The evolution of the Taiwanese IC industry provides a practical model of the emergence of the high technology industry during the 20^{th} century. The development of the Taiwanese IC industry began from the exploratory labor-intensive stage, and then proceeded through the strategic transition involved in the technology–intensive and capital-intensive stages. This study indicates that the silicon cycle of IC technology in Taiwan is seven years, as demonstrated in the introduction of 4-inch, 6-inch, 8-inch and 12-inch fabrication technologies. During the past decades, interactions among government, universities, industry and foreign leaders constituted the driver of IC industry development. Specifically, the Taiwanese government provided infrastructure, administrative assistance, and tax benefits to the IC industry. Universities were also involved, with research institutes cooperating with industry to offer strong backing for advanced technology development, and diffusing this technology into the industry to provide a competitive edge. Based on this past development experience, it is clear that high technology industries must maintain a high level of flexibility, adjusting their development direction and momentum according to the times. Furthermore, aggressive policy implementation is necessary along with leaving room for individual industry responses to environmental changes. These characteristics can provide the foundations for another industry development miracle.

This study reaches the following conclusions: (1) The cycle of silicon wafer technology in Taiwan is seven years, implying that a significant quantum leap exists between each technology cycle. All spin-off companies from ERSO/ITRI, including notable examples such as UMC, TSMC and VSIC, represented pioneers in different cycles of silicon wafer technology generation, and promoted the technological advancement of the Taiwanese IC industry. (2) Government policy and budget support is essential to creating a new high technology industry. Such support must be provided in a stepwise fashion continuously from the very earliest stages until the industry is strong enough to survive alone. This study demonstrates how the Taiwanese IC industry spent around 25 years in progressing through the burgeoning, high growth and mature phases. (3) Industrial networking among government, universities, research institutes and industry, along with strategic alliances with foreign leaders to form a vertical disintegration and cluster effect, is vital to create a competitive industry capable of making a high technology industry competitive.

Although the Taiwanese IC industry has displayed significant success in the past owing to government support, other industries have been squeezed out through the imbalanced distribution of resources caused by government intervention. The IC industry has attracted considerable talent and capital on account of its high profits, sound infrastructure and good prospects. In contrast, other industries have struggled to obtain the resources necessary for their development. This bias phenomenon in favor of the IC industry has distorted the natural process of industrial development, restricting industrial development to those industries with less government support and disadvantaging industries that do not enjoy government support.

Taiwan cannot continue to rely on current strategies for IC industry development in the future. Given the trend towards globalization and the rising challenge from China, the Taiwanese IC industry should begin to alter course and follow a new path by transforming and upgrading itself to make Taiwan into a global IC R&D center. How to make Taiwan being a global IC design hub is an excellent topic for further study. If it fails to transform itself, the Taiwanese IC industry will gradually become a traditional industry, characterized by labor-intensive production, low profits and a lack of competitiveness.

Owing to their different situations, other industries do not necessarily need to follow the same development strategy as the IC Industry. However, government support combined with integrated infrastructure, plentiful talent, competitive technology and sufficient capital is necessary to create a successful new industry. Another key factor in smooth and successful industry development is the establishment of numerous spin-off teams or companies from a single institute characterized with the same family-like culture. Moreover, vertical disintegration and the cluster effect can be formed more easily if a single enterprise culture exists.

This study describes the strategic evolution of the Taiwanese IC industry from the perspective of longitude aspect. Future studies can examine the stage dependent critical success factors contingent upon the cyclic generation of silicon technology from the 1970s to the 1990s, and the challenges involved in the strategic development of the Taiwanese IC industry after 2000. The next jump in silicon wafer technology is expected to occur in 2008 according to the pattern of a seven-year cycle established in this study. When the next technological jump occurs, large sized wafers or other advanced technologies will represent another stage in the development of Taiwanese IC industry.

The development of the Taiwanese IC industry has been successful owing to dynamic networking of a national intra-organizational system, integration of the upstream and downstream of interrelated sub-industries, and strategic alliances with leading foreign companies. Taiwan is capable of becoming a research and development hub for chip design, manufacturing, packaging and testing technologies in the IC industry. Taiwan thus holds a powerful trump card as it enters the 21st century.

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台灣積體電路產業發展的演變觀

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中文摘要
在過去的三十年當中，台灣在政府與產業界的努力之下，成功的發展出積體電路產業，帶動台灣數十年來快速與持續的經濟成長，主要原因之一很明顯的是由於積體電路產業的發展，而台灣人也引以爲傲。本研究的目的是在探討台灣積體電路產業的發展軌跡是如何產生的，本文將研究台灣積體電路產業的發展與轉換過程，此過程將透過結合文獻探討與觀察來進行縱向面的檢視，並且以勞力密集、技術密集、資本密集等三個階段進行分析。本研究顯示一個新興產業的顯現，尤其是高科技產業，有遠見的策略以建立一個健全的基礎建設的產業發展環境是充分而且必要的，本研究發現台灣積體電路產業的矽技術週期是7 年，台灣積體電路產業的發展乃得力於政府、大學、產業界和國外領導廠商之間緊密的動態網絡關係。

關鍵詞: 積體電路產業、產業發展、技術移轉、技術轉型、策略聯盟

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