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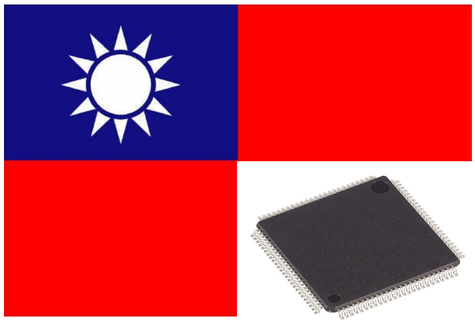
Excellent Government on a Far-East Silicon Island



The case of the Taiwanese semiconductor industry

Working paper

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Summary

With the non-existence of any semiconductor industry at all in the 1960s, to a US$ 42.02 billion worth semiconductor industry in 2006. This study attempts to identify the role of the Taiwanese government over the past 50 years in developing the technological innovation system with respect to the Taiwanese semiconductor industry.

The government has clearly taken on a leading role in initiating the development of the semiconductor industry. At what turned out to be the right moment in time the direction of national science and technology policy was set to support the industry by full means. This resulted in the creation of a non-governmental research institute (ITRI) to acquire technology from abroad, develop it intern and spin it off into industrial firms. A supportive environment for relevant firms was created by setting up the Hsinchu science-based industrial park, resulting in a cluster-effect for new firms as a result of close distance to two large technical universities and ITRI. The two biggest firms of the Taiwanese semiconductor industry as of today, UMC and TSMC, are two examples of this policy. Moreover the government put major efforts in creating a sufficient inflow of required engineers by setting up a large number of universities, supporting students to study Electrical Engineering and funding students to study and acquire knowledge in overseas universities. Taiwanese engineers who gained experience in the US and returned later on played a major role in developing the semiconductor industry.

This study includes a description of relevant organisations in the technological innovation system with respect to the Taiwanese semiconductor industry followed by a SWOT-analysis. Success factors are identified and split into context-related factors and more general factors that might function as input for policy makers in other countries. To put the Taiwanese case into perspective, a brief description is included of Dutch policy in its relevant sector and its strategic research agenda program for the Dutch semiconductor industry, Point-One.

Acknowledgements

This research was not possible without the assistance, knowledge and motivation of many among which a few are worth naming in specific. The Taiwan Institute of Economic Research, in specific director and co-writer Jason Kao, Dr. Lin and their inspiring colleagues for providing numerous useful comments and helping in logistical issues. Cristina Chen, co-writer and an important motivator and initiator of numerous interviews. Co-writers Jan-Frens van Giessel (Technopolis) and Ir. Clement Goossens (Point-One) for their contribution on the Dutch case in this research. Drs. Frans Nauta for his overseas guidance. And lastly, all the interviewees for the enthusiastic and fruitful conversations.

Abbreviations

3C	Consumer electronics, communication equipment, computers
AABI	Asian Association of Business Incubation
DoIS	Department of Investment Services
DoIT	Department of Industrial Technology
EDA	Electronic design automation
EE	Electronic Engineering
ENIAC	European Nanoelectronics Initiative Advisory Council
ESI	Embedded Systems Institute
ETA	Emerging Technology Agenda
GSA	Global Semiconductor Association
HSIP	Hsinchu Science-based Industrial Park
IDB	Industrial Development Bureau
IEEE	The Institute of Electrical and Electronics Engineers
III	Information and Information Industry
ITEA2	Information Technology for European Advancement
ITRI	Industrial Technology Research Institute
MOEA	Ministry of Economic Affairs
MRM	Multi-annual Roadmap
NBIA	National Business Incubation Association
NCKU	National Cheng Kung University
NCTU	National Chiao Tung University
NSC	National Science Counsil
NTHU	National Tsing Hua University
NTU	National Taiwan University
S&T	Science and Technology
SCI	Science Citation Index
SIP	Silicon Intellectual Properties
SoC	System on Chip
STPI	Science & Technology Policy Research and Information Centre
TEEMA	Taiwan Electrical and Electronic Manufacturers' Association
TSIA	Taiwan Semiconductor Industry Association
TSIP	Tainan Science-based Industrial Park

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1 Introduction

On September 21 1999, a 7.6 magnitude earthquake hit Taiwan causing island-wide power failures and IC production shut down of six days. Technology stock prices plunged by 10 to 15% on the NYSE. The price of 64MB DRAM modules surged from US$14 to 21 causing Dell and HP to miss production targets (Ban, 2002). The earthquake revealed the global impact of the Taiwanese semiconductor industry.

In the 1950s Taiwan was a poor agricultural based society supported by foreign aid with a per capita income of only US$ 200 a year (Berger and Lester, 2005). A semiconductor industry did not exist. Only in 1966, a US firm established the first semiconductor related subsidiary in a southern city of Taiwan, Kaohshiung. The firm was named Kaoshiung Electronics and its main activity was assembling transistors.

40 years later the Taiwanese semiconductor industry has a total revenue of US$ 42.02 billion with a growth of 23.2% in 2006. It covers all aspects including research, development and manufacturing, from low-end packaging to high-end IC design houses and mass-scale manufacturing of wafers. It is the leading industry in Taiwan in terms of driving growth. In 2006 the added value in the semiconductor industry accounted for 2.4% of GDP, a number much higher than that of other industries (Ban, 2002; Chang, 2008). The semiconductor sector now represents 50% of Taiwan's industrial production, covers 12% of its GDP and employs 80,000 people. Since 2007 Taiwan owns a global production share of 18% thus became the second largest producer of semiconductors after Japan. With respect to the world foundry market Taiwanese firms TSMC and UMC are responsible for 63% (Saunier, 2008). In 2006 Taiwan also ranked first in IC packaging and testing, and second in DRAM and IC design (TIER, 2008).

How is it possible that within 40 years the Taiwanese semiconductor industry developed from nothing to become the third largest in the world, only after Japan and the US? This result is even more remarkable when compared to other countries. For example, in the seventies the Canadian government also attempted to advance its semiconductor industry with far greater budgets. Unlike the Taiwanese case the Canadian attempt proved to be a failure (Addison, 2000)

This study shows the historical development and current status of the Taiwanese technological innovation system with respect to the semiconductor industry. It includes a description of the related and most important aspects of knowledge users (industry), knowledge generators (universities and research institutes), government intervention, the interaction and the contextual environment. Based on the results the strengths and weaknesses of the technological innovation system are revealed leading to a listing of context-related lessons and lessons which could function as considerable input for policy makers in other countries.

In order for the reader to make an attempt to compare the Taiwanese case with efforts of the Dutch government to further develop the Dutch semiconductor industry, a description of Dutch innovation policy and its strategic research agenda program for the semiconductor industry is provided by co-writing authors of Technopolis and Point-One.

2 Theoretical framework

Schumpeter was the first one to discuss the importance of innovation to economic development, which triggered academics such as Freeman (1987), Lundvall (1992), Nelson (1993) and Autio (2001) to develop concepts of national and regional innovation systems. An innovation system is the total of different subsystems which are described later on in this section. The OECD approach focuses on the flows of both tacit and codified knowledge in the interaction among enterprises, public/private sector partnerships, on the diffusion of knowledge and technology to firms and the movement of personnel. Tacit knowledge flows through informal channels, while codified knowledge refers to publications, patents and other codified sources (OECD, 1997). Although each author holds different perspectives on the concept, central is the interaction among the different players in the public and private sector to diffuse new technologies (Hsu and Chen, 2003). National innovation system theories can be grouped into general and mission-oriented definitions (Hsu and Chen, 2003). This study builds forth on the mission-oriented approach since it focuses on those interactions in the innovation system that are directly related to research and technological innovations.

The study uses a mixture of both the OECD approach and the innovation system model developed by Autio (2001) and modified by Todtling and Tripple (2005). Five subsystems in the innovation system are described according to different indicators. The subsystems are:

Users of knowledge
This subsection consists of firms that function as suppliers, customers, partners and competitors, and their supporting environment. Indicators that are used are the size and composition of industrial firms, the availability of high demanding customers, the possibilities for start-ups, coaching and training and the availability of venture capital.

Generators of knowledge
The education and research system are analysed in this subsection. The amount and quality of universities and public research institutes and their students and researchers are analysed. It also involves the organizations responsible for diffusion of knowledge. Bridging institutions between universities and industry can facilitate and accelerate the process of technological diffusion and create resources for firms (Hung and Yang, 2003).

Government
Governmental policy can play a very influential role in designing the innovation system. It is important to understand the historical development of national policy, its results in the innovation system and its current policies. Preconditions for successful policy are a clear vision and effective cooperation between departments. Interactions among the different government bodies and polices can nurture the required infrastructure needed for industrial development (Hung and Yang, 2003).

International context
In an ever increasingly global network of knowledge and supply chains, it is important to take a view on the international links between players in a national innovation system and their international counterparts.

Interaction
Intensive and interactive networks between the different players in an innovation systems are important to support a continuing flow of information and knowledge. It lowers the transaction costs due to the existence of mutual trust. A low availability of formal and informal networks and interaction can slow down innovation while a too dense form of interaction can lead to lock-in effects such as too high entry barriers for new entrants. Indicators are the availability of networks and their openness, organizations that facilitate networks and public and private funding for setting up networks.

3 Methodology

In this study based on the theory of innovation systems an effort is made to describe the role of the government in the historical development and current situation of the Taiwanese innovation system with respect to the semiconductor industry. An understanding of the innovation system with respect to a specific industry can help policy makers identify leverage points to enhance their innovative performance and overall competitiveness (OECD, 1997). Based on this it can stimulate an increasing interaction between industry, research institutes, universities and the government itself. After a historical description and a sketch of the current subsystems in the innovation system, this results into a SWOT analyses and listing of lessons which can be learned of the Taiwanese case. To put the Taiwanese case in perspective, the Dutch innovation policy with respect to its semiconductor industry is described in order for the reader to make a comparison. The study is based on an extensive literature study, supplemented by 18 interviews with different stakeholders in the Taiwanese innovation system.

4 The case of Taiwan

4.1 National key figures

To start off with an indication of the size of the Taiwanese economy some national demographic and economic figures are listed in table 1.

Key figure	Amount	Unit
Population	23.016	million
Area	35.98	square km
Population density	636	people/km2
GDP (2007)	3764.20	million US$
GDP growth (2007)	5.7	%
GDP per capita	17536	US$
Government expenditure	55311.07	million US$
Government expenditure/GDP	14.7	%
Imports (2007)	219250	million US$
Exports (2007)	246680	million US$
Trade surplus (2007)	27340	million US$
Approved Overseas Chinese and Foreign Investment (2007)	15361	million US$
Approved Outward Investment (2007)	6470	million US$
Inflation (%) (2007)	1.8	%
Working population (million)	10522	million
Unemployment rate (2007)	3.91	%
Start-ups per 1000 people	unavailable	number
Researchers per 1000 employees	8.90	number

Table 1. National key figures of Taiwan (numbers are from 2006, unless cited otherwise) (Website National Statistics ROC, 2008-12-04; Website MOEA, 2008-12-04; NSC, 2007).

4.2 Historical development of the semiconductor industry

1960-1970

In a historical view of semiconductors, the microelectronic silicon computer "chips" started with a single transistor in the 1950s (Moore, 1965). In 1959, Fairchild Semiconductor in the U.S. began with the development of an integrated circuit based on Hoerni's planar process and Noyce's patent. The company presented advanced information and provided prototype samples to customers in 1960. This approached the first planar IC to be fabricated and applied widely in computer, telecommunication, electronic products and machineries. In the start of the electronics industry, integrated circuits part played a vital role.

At the same time in Taiwan with the basically non-existence of a semiconductor at this early stage of time, the government focused on export-oriented promotion strategies and import substitution, establishing export-processing zones (EPZs) to bring in foreign technology and capital (Terence Tsai and Zhou, 2006; Chu, 2003). From the start the role of the Taiwanese government has been strong in order to lead an emerging industry (Kao, 2008). In the 1960s during the now famous "soybean breakfast meeting" policy makers selected the IC industry as a strategic emerging industry for the focus of development (Chang and Hsu, 2001). The government enforced Taiwan's economic development via the Statue for Encouragement of Investment (SEI) and Improving Statue for Upgrading Industries (IUS) (Lin, 2005). In 1966 these efforts attracted the first semiconductor firm to Taiwan being the subsidiary Kaoshiung Electronics of the US firm General Instruments, focusing on low-end assembling (Hsu & Chen, 2003). Other firms followed by shifting their low-end production sites to Taiwan among which Philips Packaging. Attracted by financial incentives from the Taiwanese government and the availability of a cheap labour force these firms brought in capital and technology on IC packaging, testing and quality control (Chang and Hsu, 2001). During this period the only way for local Taiwanese firms to engage in packaging activities was in serving as OEM manufacturers for their foreign customers (Cheng, 2006). In Korea some multi-corporations such as Signetics, Motorola, Control Data, AMI and Toshiba duplicated this OEM business model.

In academic circuits of Taiwan the theory and technology of semiconductors were first introduced when the National Chiao-Tung University started a related course in 1960. In 1964 it set up the first semiconductor lab which resulted in the actual manufacturing of the first IC in 1965. Though, relations between universities, research institutes and the few firms that started production more overly did not exist at that time (Kao, 2008).

1970-1980

In the early seventies the Taiwanese government continued to take on a leading role in industry development. In 1973 assembled-electronic products became the main export products relying on cheap labour. Realizing these labour-intensive industries combined with Taiwan's scarce natural resources and limited domestic market, would become the bottleneck for economic growth in the future, The Taiwanese premier and minister of Economic Affairs in consultation with academics and members from local and foreign industries, decided to promote and take charge of developing the semiconductor industry by full means. This decision was debatable on many issues and questions arose on beforehand whether Taiwan really needed an IC industry and moreover whether it would ever be able to acquire sufficient resources and qualifications to develop an IC industry and engage in international competition. Known today as the godfather of Taiwan's science and technology policy, K.T.Li argued that full employment in labour intensive sectors would be reached around 1980 making expansion impossible (Cheng, 2006). As it turned out later the appointment of the semiconductor industry as the strategic industry was the right technology direction at the right moment (Lin, 2005).

Meanwhile U.S. leading technology firms Fairchild and Motorola offered early MOS standard cell capabilities under the trade names Micromosaic and Polycell. With previous experience that local Taiwanese firms were unable to develop semiconductor technology themselves and an unwillingness of foreign firms to shift higher-end production sites to Taiwan, the Taiwanese government realized intervention was necessary (Cheng, 2006).

Since a semiconductor industry would require a high level of research and technology development, the minister of Economic Affairs Dr. Sun Yun-Suan decided the strategy should be to set up a non-profit research institute to ensure flexibility without government control (Huang, 2006; Hsu and Chen, 2003). Dr. Sun's plan faced huge resistance before being approved by the Assembly House. This reform would have never occurred without the full support of the national president of that time, Chiang Ching-kuo. As a merger of three existing research institutes and relocation to Hsinchu the Industrial Technology Research Institute (ITRI) was born in 1973. Dr. Sun is nowadays remembered as "the father of ITRI". The initial budget of ITRI was only US$ 6.3 million for 400 researchers. In 1974 ITRI set up the Electronic Industry Research and Development Centre (ERSO) to assist the development of the semiconductor industry. The ERSO started a project in 1975 to develop an IC demonstration. To acquire the needed technology and human resources it followed the advice of the Technology Advisory Committee (TAC) to acquire CMOS technology from abroad. The TAC, consisting of overseas Chinese mainly in the US and headed by Dr. Pan Wen Yuan, was set up for organising technological cooperation as well as playing an advisory role (Terence Tsai and Croft, 2006). The low power and high density CMOS technology with sub-micron development potential was chosen as the foreign technology to acquire. Although firms in the US were already developing 3.5-micron technology, the TAC decided to transfer 7.0-micron technology since it was mature and therefore affordable, proven and well documented. If the transfer would be successful ERSO was expected to be able to upgrade it internally to 3.5-micron technology (Hsu & Chen, 2003). The TCA selected the US firm RCA and signed a technology licensing agreement, which involved the training of 38 ERSO employees by RCA in the US and the recruitment of US engineers to ERSO (Lin, 2005; Chang; Chang and Hu, 2001).

The RCA project had a budget of US$ 12 million (Siao, 1994). The Taiwanese engineers sent to RCA brought back the basics of all different production steps in the value chain of semiconductors.

The trained ITRI engineers not only acquired technical knowledge and skills, but also overall industrial technology of engineering and operation management (Chen, 2001). ERSO internally developed the technology further and built the first IC chip in its IC demonstration plant in 1978 (Chang and Yu, 2001). This plant functioned as the main support and development centre for the incubating semiconductor industry. "We all knew that a demonstration plant had to be operated after we would return to Taiwan, so every detail in the plant had to be figured out", Dr. Shih recalls (see box 1) (Chen, 2001).

Box 1. Dr. Shih Chintay
Dr. Shih Chintay, former president of ITRI was one of the team leaders to transfer the CMOS technology from RCA to ITRI. He remembered that time as highly uncertain, while relying heavily on the expertise of the members of the TAC. "The TAC were our tutors and lighthouse. They have contributed the rest of their lives without any payback." The TAC members have been ITRI consultants since that time until now. Dr. Shih is now professor and dean in the College of Technology Management, National Tsing Hua University and volunteered as Chairman in ITRI.

At the same time the government stimulated investment by setting up an investment fund of the Executive Yuan (Taiwanese cabinet) and coordinated the government-owned Chiao Tung Bank to provide refinance and loans (TIER, 2008). However, since the semiconductor industry was too small and investors were unfamiliar with the technology in this period of time so the venture capital industry took off only in the 90s.

With respect to human resources a high-tech semiconductor industry would require a continuous input of high-tech engineers. The government promoted engineering studies within universities and funding for students to study and gain experience in universities in the US. When these students returned to Taiwan the government would arrange high-positions for them in research institutes like ERSO. Since ITRI would not place any barriers on employees transferring to industry, the industry would profit later on when these returnees continued their careers in local firms (Chu, 2003; Hsu and Chen, 2003).

As the government fully supported new technology development the Technology Development Program (TDP) for Research Institutes was implemented by the Department of Industrial Technology (DoIT, under the Ministry of Economic Affairs, MoEA) since 1979 (Hsu & Chen, 2003). TDP plays an important role in the development of key technologies for industrial needs and accelerates industry upgrading. The annual budget for TDP was NT$100 million (around US$ 2.5 M) in its initial year (Hsu & Chen, 2003).

1980-1990

The 1980s are characterized by a most influential role of ITRI in spinning off technology and many resources, and an important role of the government in setting up a supportive science-based industrial park. Venture capital was introduced by American-Chinese experts from Silicon Valley who had an influence on government project investments in high-tech industries and enjoyed tax reduction incentives for risky investments.

The IC demonstration plant with acquired technology from RCA was spun off in the first Integrated Device Manufacturing firm of the Taiwanese semiconductor industry, United Microelectronics Corporation (UMC). The whole project was planned by ITRI including the transfer of process and product technologies and personnel and the training of new personnel (Huang, 2006; Terence Tsai and Zhou, 2006). Although the program was supported by the government and ITRI, UMC had difficulty in raising capital reflecting the conservative view of venture capitalists with respect to the semiconductor industry. Therefore UMC raised capital from its employees who became employees and shareholders at the same time (Cheng; 2003) Later on this process evolved in a industry generic but unique employee-profit sharing system which became the most attractive factor for young engineers to join the high-tech industry. UMC started production in April 1982 and broke even in November of the same year. In June 1983 its turnover exceeded US$ 3 million a month and customers originated from Taiwan, Hong Kong, Korea and the US (Hsu and Chen, 2003). The first successful spin-off of ITRI, based on the acquired CMOS technology from RCA, was a fact.

To create a supportive environment for high-tech firms the government created the Hsinchu Science-based Industrial Park (HSIP) in 1980. The government realized that proximity near human resources was favourable. Since both the National Chaio Tung University (NCTU) and the National Tsing Hua University (NTHU) and also ITRI were located in Hsinchu this site was selected to become HSIP (Chang and Hsu, 2001). Services provided to HSIP inhabitants were tax incentives and a one-window administration service. UMC was its first inhabitant. The successful spin-off of UMC of ERSO was followed by other spin offs such as Syntec, Wel Trend Semiconductor and SIS (Hsu & Chen, 2003). Among these the most remarkable was the founding of the first dedicated foundry in 1987, TSMC. Morris Chang is regarded as one of the key figures in the success of the Taiwanese semiconductor industry (see box 2).

Box 2. Morris Chang

Morris Chang graduated from Harvard, continued at MIT's graduate program and gained a PhD at Stanford University. After a 20-years career in the US as vice president of Texas Instruments and president at General Motors, he accepted the invitation of the premier of the Executive Yuan to come back to Taiwan to become the president of ITRI. He came back to Taiwan because of the premiers appeal to him to use his capabilities to transfer research results at ITRI to industrial applications. It was the new exciting challenge which was the most important reason for Morris Chang to accept the invitation. If it was for financial reasons a career in the US was more fortunate . Only weeks after his return to Taiwan, Mr. K.T. Li asked him to write a business plan and tell the Executive Yuan how much money he needed. Morris Chang analysed the Taiwanese semiconductor industry and concluded that there was nothing except some potential in wafer manufacturing. His choice for a pure foundry, in his own words the 'least evil choice', was perceived as impossible by government officials since there was no market yet. Morris Chang convinced them with his plan as a result of his experience in US firms of which he expected a lot of IC design spinoffs once a dedicated foundry service would provide the capital intensive but critical step in wafer manufacturing. In 1987 he founded the first dedicated foundry which changed the global structure of the semiconductor industry (Interview with Morris Chang, 2007).

In 1987 he invented the dedicated foundry business model by spinning off TSMC from ITRI (Chang and Hu, 2001; Huang, 2006) in the process changing the working of the entire international IC industry (Fuller, 2002). ITRI formulated three requirements for the spin-off. It should be a dedicated IC foundry, a joint venture with an international company and all possible resources of ITRI should be transferred. Of the foreign enterprises invited by Morris Chang only Philips showed interest and gained 26% of the Initial Public Offerings (IPOs). ITRI leased its Very Large Scale Integration (VLSI) plant and transferred 150 engineers to TSMC (Hsu & Chen, 2003). TSMC's founding was the top of the iceberg and successful ending of the earlier started VLSI program in 1983 with a total R&D expenditure of US$ 57.5 million (TIER, 2008).

Dedicated foundries offer manufacturing facilities and thereby allowing IC design firms to operate without having the need for building their own manufacturing capabilities and therefore decreasing the risks and needed capital for IC design firms (Hsu & Chen, 2003). The key factor in the success of the dedicated foundry model is that foundries do not have their own branded products (Lin, 2006). Therefore with increased protection from being copied IC-design firms were eager to bring their designs into production at TSMC and TSMC in turn can obtain a steady usage of capacity. Other strengths of TSMC are the facts that it manages to have a flexible manufacturing capability and a highly customer-oriented service (Lin, 2006). The success of TSMC led to the establishment of many related IC firms among which are MOSEL, SiS, MXIC and Winbond (Chang & Hu, 2001). By 1987 30 IC Design firms accounted for US$ 32 million of sales (Hsu & Chen, 2003; ITRI, 1992) (Chang, 2008). And TSMC managed to acquire the latest technologies by providing foundry services to large multinationals in exchange for transfer and licensing of technology (Chen & Jan, 2005). Inspired by the success of TSMC, UMC decided to change its IDM character to a dedicated foundry as well. In 1999 both TSMC and UMC accounted for 67% of the global foundry market (Wu, 2001).

The number of venture capital managing firms increased slightly during 1984 to the early 1990's (TVCA, 2004). Large investments in IC design firms after the founding of both UMC and TSMC with high growth potentials increased the demand for masking services which completed the IC value chain from design to manufacturing. ITRI transferred staff and technology to its spin-off TMC and signed a 10-year contract for technology transfer and joint development (Hsu & Chen, 2003). This stimulated even more domestic investments leading to the creation of many IC design houses (Huang, 2006). In a period of less than 20 years the government had created and adjusted a research institute which acquired and developed semiconductor related technologies which were spun off into multiple successful local firms. Although the government was therefore highly involved in generation and incubation of technology into start-ups it gave the private sector full control over production and commercialization of the technologies, instead of creating state-run firms (Cheng, 2006).

1990-2000
In the 90s the global market for semiconductor components shifted from one dominated by personal computers (PCs) to a more diverse array of heterogeneous niches associated with the internet and wireless communications applications. IDMs no longer dominated industrial production and innovation. Instead a vertically integrated industry segment coexists with a vertically specialized or disintegrated segment. IDMs compete and often collaborate with firms specialized in either design or marketing (fables firms) or manufacturing (foundries) (Jeffrey T. Macher, 2008). The Taiwanese industry showed more and more alliances and offshore relocation of manufacturing (Jeffrey T. Macher, 2008). With respect to the Taiwanese government, this period marked the shift of a leading role from the government to a stronger role of the industry itself (Trappey and Chen, 2001). One example is the termination of direct financial support from the government to ITRI in 1994.

Dr. Pan Wen Yuan passed away in January 1995 shortly after his beloved industry in Taiwan established an advanced 8-inch wafer by the ITRI spin-off company Vanguard which was recognized as one of the world leaders in manufacturing technology (the Foundation, 1996). Vanguard was Taiwan's first spin-off based on self-created technology and induced an investment boom in both 8-inch wafer- and DRAM manufacturing (Huang, 2006).

4.3 Innovation system as of today

A graphical image of the innovation system is depicted in figure 1. The different subsystems are described in the following sections.

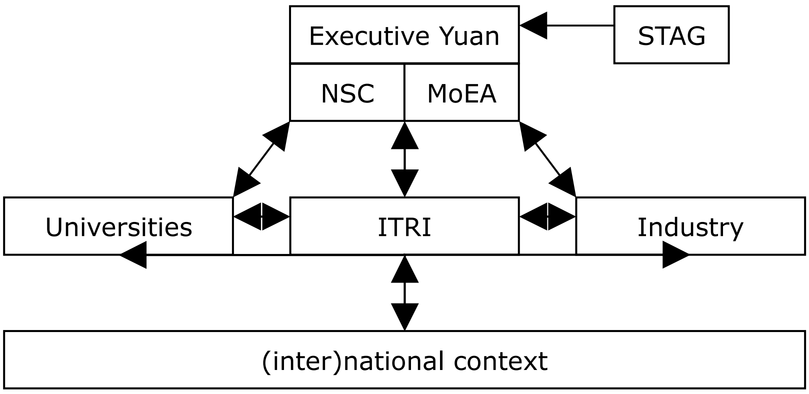

figure 1: National innovation system of Taiwan's semiconductor industry

4.3.1 Users of knowledge: Industry

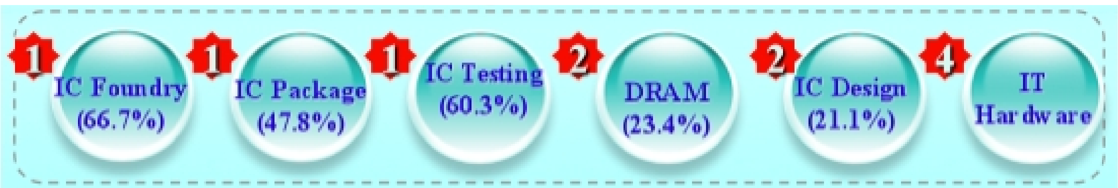

figure 2: Global ranking of Taiwanese semiconductor industries (excludes overseas production) (Presentation SIPO 2008-11-11: ITRI IEK, 2007/4)

Taiwan's semiconductor industry consists of over 400 firms, with a total revenue of US$ 42.02 billion in 2006 and a 24.6% growth over 2005 (ITRI IEK, 2007/4). Taiwan hosts 16 12-inch (300mm) fabs and another 19 are planned to be established in the near future (SIPO presentation, 2008; Ban, 2002; TSIA, 2007). Critical mass in terms of a large amount of firms and total turnover, is therefore abundantly present in the Taiwanese semiconductor industry. As the opposite to Integrated Device Manufacturers in Korea, Japan and the US, most of the semiconductor industry of Taiwan is characterized by a high degree of vertical disintegration which includes different firms in different stages of the semiconductor product and development chain (see box 3). The world ranking of these different stages in the value chain are shown in figure 2. Only a few successful Taiwanese IDMs exist, for example Macronix International (Jen, 2006). The vertical disintegration reflects the Taiwanese mentality of rather being the boss of a small business then a regular employee in a large firm. Each firm develops its own core competencies and expertise that allow it to become very good in its specific field, optimize the utilization of its capacity and reduce manufacturing cycle time. The virtual integration off all the different firms pulls the whole system together into an integrated supply chain of materials and knowledge (Li & Shuai, 2001).

Box 3. IDM vs. vertical disintegration

Two types of IC production system exist. Integrated device manufacturing (IDM) refers to firms that include IC design, fabrication, packaging, and testing all in one single firm. The other type of system is vertically disintegrated and separates the independent production systems in different firms: IC fables-, wafer fabrication-, mask generation- and fabrication-, IC packaging-, and testing firms. In this system, every firm focuses on one step in the production-chain of ICs.
(Hung and Yang, 2003)

A small number of large firms takes account for a large share of the total revenue. For example, the top ten largest firms account for almost 25% of the total output in the semiconductor industry. Out of these top ten Taiwanese IC manufacturers six are also in the global top 10 IC manufacturers (ITIS, 2008). However over 97% of industrial firms in Taiwan comprise small and medium enterprises (Hsueh and Okrasa, 2003).Taiwan's SMEs are masters in low-cost production and quick response to changes in markets and technology (Ernst, 2006). As a result of the large number of SMEs and high degree of vertical disintegration SMEs tend to be suppliers, customers, partners and competitors with each other and the larger firms. They compete each other in the search for customers and engineers while collaborating in orders which are too large for one SME to deliver on its own (Interview with SIPO, 2008-11-11). It is not rare for Taiwanese SMEs to invest in each other in a supplier-customer relation (Hsu and Chen, 2003). An interesting example of attracting human resources and create more commitment among employees is the earlier discussed unique employee-stock ownership system. Instead of a high salary firms offer employees attractive stock and bonus options, which will increase in value as the firm makes more profit (see box 4).

Box 4. Value-shared bonus system

Initially adapted from the US and Europe and promoted by the government, Taiwanese firms use a value-shared bonus system which allows employees to become company stockholders and are paid generous bonuses in terms of company stocks. This system attracts experts from local and overseas, builds company loyalty and motivates employees (Li & Shuai, 2001; Chen & Jan, 2005; Chen & Wang, 2001). One dark side of this system is actually a diminished company loyalty when bright employees put a stock value on themselves available to the highest bidder. But overall the system is widely regarded as a positive stimulant for the development of the industry and is the main reason for employees to join or leave a company (Chen & Wang, 2001). Nowadays large firms provide less high stock options than before which results in employees switching to higher paying international firms (Interview with ITRI IEK, 2008).

The percentage of in-house R&D is low both in large as in small and medium enterprises. Large firms rely on their foreign partners for supporting technology acquisition (Jan & Chen, 2006; Interview with TTSC, 2008). SMEs focus on cost competition and simply lack the resources and sufficient engineers to conduct in-house R&D (Jan & Chen, 2006; Interview with SIPO, 2008). In the words a manager of an SME: "We are just trying to make money" (Berger and Lester, 2005). The reliance on foreign firms for technology is reflected in the amount of technology imports, US$ 1553.8 million, against the almost six times lower technology export amount of US$ 266.4 million (NSC, 2007). Although Taiwan's R&D expenditures have grown in the last few years both in absolute and in expenditure per capita it is still far behind the R&D expenditures of Japan and the US.

In 1998, the expenditures on R&D per capita were 1/3 of the same number in Japan, and 1/4 of the same number in the US (Hung & Yang, 2003).

High-demanding customers are some Taiwanese firms (for example Acer and Asus) but moreover foreign multinationals. These multinationals demand high quality products against the lowest prices (Interview with Topology, 2008). These high demanding customers are and have been in the past the driving forces behind the growth of the Taiwanese semiconductor industry. Taiwanese firms themselves are heavily dependant on Japan, the US and the Netherlands (ASML) for its equipment for wafer and IC manufactures and IC-design tools (Hung and Yang, 2003: Interview with AMSL, 2008). The supportive environment of firms in the industry consists mainly of the services provided by the science parks (see section 'government'), research institutes (see section 'generators of knowledge'), and network organizations such as the Taiwan Semiconductor Industry Association (see box 5).

Box 5: Taiwan Semiconductor Industry Association (TSIA)

The TSIA was initiated by the ERSO in ITRI in 1996 and in 2002 its members accounted for 82.9% of total sales of the semiconductor industry. The organization is seated by a president from industry and six fulltime employees. In the beginning funding came from ERSO, nowadays solely from its members. It provides (inter) national networking activities and seminars to promote local and international collaboration among its members. Annually two or three international conferences and four local conferences are organized. Other services are consultation (patent, environment) and training services, providing suggestions for government policy (to IDB) and engage in international negotiations. Training services are provided in cooperation with NCTU which fees are covered for 50% by the government (website TSIA, 2008-11-13; Interview with TSIA, 2008).

Start-ups are supported by over a 100 government-funded incubators within universities, technical universities and research institutes. With respect to venture capital US$ 5.33 billion was available among 270 venture capital funds managed by 101 venture capitalists in 2006 (see box 6). Although theses venture capitalists moreover invest in expanding stages of growth, new entrepreneurs are able to find seed capital from friends and family (Interview with PVP, 2008). The government assists in fund raising by providing special low-interest loans for technology related R&D investments in cooperation with banks via the Development Fund. In addition the government provides mid-to-long term financing (up to US$ 3 million) for investment projects of private firms. For SMEs, the non-profit Small and Medium Business Credit Guarantee Fund, a joint fund of the government and financial institutions, provides credit guarantees to qualified firms (website IDB, 2008-11-20).

Box 6. Venture Capital

The Taiwan venture capital industry was established in 1984, rapidly developed after 1995 and went into freefall after 2000 caused by the governments decision of eliminating the tax credit for venture fund investors and the worldwide economic recession. Although venture funds have gradually lost their ability to invest in start-ups and emerging risky technologies partly because large mature firms invest in these start-ups themselves, the investments in expansion-stage firms by venture capitalist is still abundant in Taiwan. Of total investments the semiconductor industry received the largest share (18.34%) in the year 2006 and also in total accumulated from 1984 to 2006 (18.10%). Venture capitalists sometimes compete in investing in the most profitable firms but moreover work together as partners in the search for new profitable investments (Interview with PVP, 2008: TVCA, 2007). They are connected by the Taiwan Private Equity & Venture Capital Association (TVCA) which provides them with networking activities and information about the industry. When an entrepreneur is in need of capital, venture capitalists are easy to be found as a result of the extended network between venture capitalists and industry (Interview with PVP, 2008). Investors may apply to the government to invest in their projects up to a maximum of 49% of total capital (SIPO presentation, 2008-11-11). Though venture capitalists do not require government involvement. Moreover, the government could support the venture capitalist industry by allowing them to invest Taiwanese capital directly in Mainland China (Interview with PVP, 2008).

One characteristic of Taiwanese venture capitalists is that they prefer stock dividends above cash dividends which makes it easier for high-tech firms with good prospects to raise funds while reserving their revenues for investments rather then distributing it to shareholders (Chen & Jan, 2005). However, some local firms complain that venture capitalists in Taiwan compared to US venture capitalists are mainly focused on the balance sheet of a business plan instead of the technology involved (Interview with Opus, 2008).

4.3.2 Generators of knowledge: universities and research institutes

In this section the contribution of the relevant research institutes and the university system is described.

Industrial Technology Research Institute (ITRI)

R&D staff	5744
Ph.D.	917
Total number of patents	7245
Total number of start-ups	140

table 2. ITRI key figures (Website ITRI, 2008-12-04)

Initiated by the minister of economic affairs, Mr. Y.S. Sun, ITRI was set up in 1973 as a non-profit, government funded national research organization with the goal to enhance industrial technologies and serve as the building bridge between government, universities and industry (Huang, 2006; Hsu and Chen, 2003). Although ITRI was based on the Japanese governmental National Institute of Advanced Industrial Science and Technology and the Korean Public Institute of Science and Technology, ITRI was specifically a non-governmental non-profit organization to insure operational flexibility and freedom from government control (Hsu and Chen, 2003). Its mission is to support the industry by upgrading industrial technology, implementing government industrial policies through developing future technologies, assist SMEs in upgrading their technology and cultivate industrial technology specialists (Chang and Hsu, 2001; Huang, 2006). Therefore it adopted a 'push-pull' system balancing the pulling of demand articulation from local industry and pushing technology into industry (Huang, 2006). ITRI acquires technology from abroad, develops new technology and diffuses it to industry through spin-offs, technology transfers, seminars and human resources. With respect to technology advancement, within only 20 years ITRI managed to process IC know-how from far behind international standards to almost competing with the US and Japan (Huang, 2006). In 2006 it transferred technology for 694 items to firms in Taiwan with a total value of US$ 41.56 million. In the same year 2,302 patent applications were made and 985 domestic and foreign patents were obtained by ITRI (website Taiwan, 2008-11-16). ITRI has six major fields of which Communication & Optoelectronics and Nanotechnology are related to the semiconductor industry (Jan & Chen, 2006). ITRIs budget was US$ 500 million in 2006, of which 54% (compared to 90% in the 1970s (Huang, 2006)) came from government-supported technology development programs and 46% from industrial firms for provided services (Jan & Chen, 2006).

In 2006, 6100 employees were employed at ITRI among which were 871 PhD's. 120 of the latter were sponsored by ITRI to gain their doctorate degree for example at Stanford or MIT in the US (Huang, 2006). In 2006 ITRI recruited on average 100 PhDs to replace 90 resigning employees while the average annual total turnover is around 800-900 employees. ITRI attracts researchers who favour their individual development in an open and free work environment and humane management system (Tzeng and Lee, 2001). Since ITRI sets no restrictions on its engineers to transfer to industry it has made a major contribution to the semiconductor industry by spinning of personnel. From 1973 tot May 2000, 13,995 employees of which 85 % moved to industry (of which 24% to IC related firms) and 15% to universities and government. 40% of the managers in HSIP based firms are ex-employees of ITRI among which 60 are at CEO level (see for example table 3) (Huang, 2006; website ITRI, 2008-12-09).

Name	Position in ITRI	Current Position
Morris Chang	Chairman	Chairman, TSMC
Fan-cheng Tseng	Plant Manager	GM, TSMC
hsin-Cheng Tsa	Deputy Head of Division	Chairman, UMC
Ming-Tze Hsuin	Manager	CEO, UMC
Yin-Dar Liu	Manager	Executive Director, UMC
Chin-Rung His	Manager	GM, UICC
Bi-Wan Chen	Manager	GM, Taiwan Mask
Ding Hwa Hu	Vice President	Chairman, Macronix
Ding-Yuan Yang	Director	Deputy Chairman, Winbond
Ching-Jiu Chang	Head of Division	GM, Winbond
Tse-Yuang Lu	Deputy Head of Division	Chairman, SC
Kuo-zao Wang	Manger	GM, Syntek
Bing-Tien Wu	Head of Division	GM, HC
Chi-yong Wu	Chief of Section	Chairman, Holtek
Ming-Jie Tsai	Manager	Chairman, Novatek
Si-Ming Lin	Supervisor	GM, WC

table 3. IC industry executives with an ITRI background (Huang, 2006)

ITRI cooperates with industry in four different ways. It provides technical consultation, joint research projects, start-up support in it's Open Lab incubation centre (see box 7) and training services for industry personnel in cooperation with universities.

The role of ITRI has changed over the years. Since large Taiwanese firms nowadays have sufficient capital to conduct some internal R&D and acquire equipment and technology from international leading firms and because of the fact that a lot of ITRI personnel has moved to industry, ITRI is focusing more on conducting cutting edge research which is still too risky for large firms to conduct themselves (Chang and Hsu, 2001). Currently three programs are relevant to the semiconductor industry being MRAM (memory), 3D-IC (packaging) and System-on-Chip-projects (SoC). Large firms are involved in this joint research in expressing their technology needs and set the direction of this cutting edge research within ITRI. They also share resources like manufacturing capacity and benefit in terms of discovering talented ITRI staff early on (Interview with ITRI IEK, 2008; Hsu and Chen, 2003). IEK is involved in researching the application opportunities of the research on the market. After the technology has been developed the results will also be diffused to SMEs via seminars. ITRI holds about 900 sessions and activities attended by 60,000 people each year (Jan & Chen, 2006). SMEs ideally select the technology they can use and give feedback to ITRI in terms of adjustments. Although in some projects professors and their students are involved the interaction with universities in this cutting edge research within ITRI is limited (Interview with ITRI IEK, 2008). Furthermore ITRI serves as a technical partner to industry by providing contract services to conduct R&D and technical services like testing and professional training of employees. Each year around 25,000 firms request ITRI to provide technical services.

Box 7. ITRI's Open Lab & incubation centre
In 1995 the government started policy on funding incubation centers and selected ITRI as the first target (Interview with TTSC, 2008). ITRI set up the TTSC Open Lab in 1996 to support firms by doing cooperative research and facilitate startups in offering facilities, share knowledge and assistance including legal and financial consultations (Hsu and Chen, 2003). At present 255 firms have used the program of which 150 startup firms. Total investments accumulated to US$ 1.457 billion (website ITRI, 2008-11-13). Within the Open Lab an Incubation Centre supports its startups with management advice and technical consulting services. For the entrepreneurial experience it hires 'entrepreneurs in residence' who pass their experience from industry on to the young entrepreneurs in the centre. The centre also provides access to capital through the Industrial Technology Investment Corp., an in-house venture capital fund that has invested more than US$15 million in about 30 incubator clients and assists its startups in acquiring other funding and useful connections. Both entrepreneurs from outside ITRI as of ITRI researchers can apply to rent space in the incubation centre. The requirements are that a new firm is to be established within 18 months and that cooperation involves an ITRI team. In addition ITRI researchers, although not explicitly cited on beforehand, are given the chance to return to ITRI in case of failure. Although about three-fourth of ITRI applicants ask about their options in case they might fail setting up a business, half of them finds it not that hard after all (Interview with TTSC, 2008). With respect to existing firms who make use of the incubation centre the firm STAR indicates that most appreciated aspects of the centre are its guidance in the search for government funding, it's promotion by road shows, the availability of ITRI engineers and the support in finding customers (Interview with STAR, 2008). The centre has been recognized internationally by two awards of the NBIA and the AABI (Website NBIA, 2008).

To support the government in the development of industrial policy and centralize the marketing offices within ITRI of its technology, ITRI founded the Industrial Economics and Knowledge Centre (IEK) to conduct R&D projects for evaluation of existing industry systems and suggesting proposals for new industry areas. In this way ITRI has been more involved in influencing the direction of influencing industrial policy (Jan & Chen, 2006; interview with ITRI IEK, 2008). The IEK consists of 150 researchers of which 18 are working on semiconductor industry related subjects. A large number of IEK researchers have experience in industrial firms (Interview with ITRI IEK, 2008).

To satisfy the demand for training by HSIP firms, SIPA, NTCU, NTHU and ITRI jointly conduct professional training programs in high-tech fields. 24,390 persons have been trained between 1993 and 1998. To make higher education more accessible for HSIP employees MoE has authorized a Masters-Degree-on-the-Job program (Chang and Hsu, 2001). To further fulfil the role as creator of talent the ITRI college was founded in 2003 offering professional training courses taught by experienced research within ITRI (Jan & Chen, 2006). Other training institutes are the Institute for Information Industry (III) (175,000 trainees between 1980 and 1996), the National Nano Device Laboratories (NDL) (730 IC-related trainees annually), and the NDTU Submicron Professional Training Centre (11,000 trainees between 1991 and 1998).

Academica Sinica
The Academica Sinica is the main conductor of fundamental research. It is directly responsible to the President of the ROC and has autonomy in formulating its own research objectives. With a total budget of US$ 254 million (2006) it encompasses 31 research institutes in a variety of research fields. The academy employs 247 academics (2/3 overseas) of which 42% is active in the field of mathematics and physical sciences. 900 research fellows and technical staff (96% PhD) and 600 post-doctoral research fellows (website Academica Sinica, 2008-11-16; NSC, 2008). The academy exchanges knowledge with the top universities via research fellows from Academia Sinica that own second appointments in terms of professorships in these universities. For example, current president Chi-Huey Wong with experience in MIT and Harvard is also a professor at the NTU. Furthermore it offers PhD programs to (inter)national applicants (Taiwan International Graduate Program). In total 1894 students are employed at the academy of which 1021 are Ph.D. Students, 802 Master's degree students and 71 students with no degree yet (website Academica Sinica, 2008-11-16). The interaction with industrial firms has been limited and therefore the Academica Sinica has made less contribution to the industrial development of the Taiwanese semiconductor industry (Chen & Jan, 2006). The academy has influence on the choice of technology direction by the government (Interview with Jason Kao, 2008).

Universities

Taiwan is home to 159 universities. In the university year 2005-2006, 1,259,490 students enjoyed university and college education (website MoE, 2008-11-13). The Taiwanese culture places a large emphasis on higher education and every year the education system produces at least 20,000 graduates with a master or doctoral degrees (Yu and Chianglin, 2001). Four universities are regarded as Taiwan's top universities among which the National Taiwan University enjoys a ranking in the Times Higher Education Top 200 World Universities of 2005 and 2006 (website Times Higher Education, 2008-11-13). The other top three universities include the National Cheng Kung University, National Chiao Tung University and the National Tsing Hua University (website Institute of Higher Education of Shanghai Jiaotong University, 2006). Among these the NCTU is historically seen as the cradle of the semiconductor industry as it acquired expertise in high technology and diffused it to other universities thereby broadcasting the needed education in the early days of the semiconductor industry (Chang & Yu, 2001). The growing number of universities in Taiwan is a result of recent policy to stimulate the growth of this number which has resulted in higher education for more students. According to the "Labour Force Evaluation Measure" (LFEM) reported by BERI in 2005 the quality of the workforce in Taiwan ranks third in the world following only Singapore and the USA (Website IDB, 2008-11-20). However, the university system reveals certain downsides as well. First of all some argue that the large number of universities has resulted in decreasing levels of the quality of education and students and in a shortage of appropriate engineers in Electrical Engineering (EE) (Interview with SIPO, 2008; Interview with Opus, 2008). The forecast for demand and supply of graduates in EE for 2008 showed a demand of 3,200 graduates against a supply of only 1,700 Electrical Engineering students. A survey among firms showed that they prefer graduates in EE only from the top four universities which decreases the supply number to only 1398 (82% of total supply) (see table 4). Although the forecasts for 2009 and 2010 show that in 2010 supply will surplus demand, Taiwanese firms still argue that there will be a talent shortage in the future as they regard only graduates from the top four universities (Presentation SIPO, 2008; Market Intelligence Centre, 2008). Most of the top graduates in EE choose a career in large firms such as TSMC, UMC and Mediatek. As a result, the burden of finding qualified engineers is especially carried by high-tech SMEs (Interview with SIPO, 2008-11-11; Interview with Acer, 2008-11-14; Interview with Opus, 2008).

	Master	PhD	Total
NTU	723	99	822
NTHU	124	12	136
NCHU	170	40	210
NCKU	201	29	230
Total			1398

table 4. Number of EE graduates in 2008 from top four universities (Market Intelligence Centre, 2008)

A second matter of concern is the high emphasis within universities on strict examination. Since students are a large part of their time working on reports and rehearsing exams, they are not triggered in developing their own creative way in problem solving. As a result although students gain deep technological knowledge, a creative mind is argued to be lacking among students (Yu & Chianglin, 2001; Interview with SIPO, 2008-11-11; Interview with Prof. Wang. 2008-11-09)

In the early days the government provided grants to the best students to study in the US to gain overseas experience. Current president Ma Ying-jeou is an example of this policy. The overseas students that returned to Taiwan either due to love for their country or due to US economic depressions, made a significant contribution to the semiconductor industry of Taiwan. At the end of 1998, 3056 returnees had positions in firms in HSIP and were responsible for the start-up of 109 firms (Chang and Hsu, 2001). Between 1983 and 1987 most overseas students in US universities were Taiwanese (see figure 3). Nowadays their numbers are declining with less and less Taiwanese students studying in the US and other countries abroad (Chen & Jan, 2005). Between 1995 and 2004 the number of Taiwanese students studying abroad decreased with 30% (website MoE, 2008-11-13). Consequences are graduated students to lack overseas knowledge and experience (Interview with prof. Wang, 2008). Therefore the government now aims to recruit more overseas students to study in Taiwan and thereby bringing overseas talent to Taiwan (Interview with Prof. Wang, 2008-11-09).

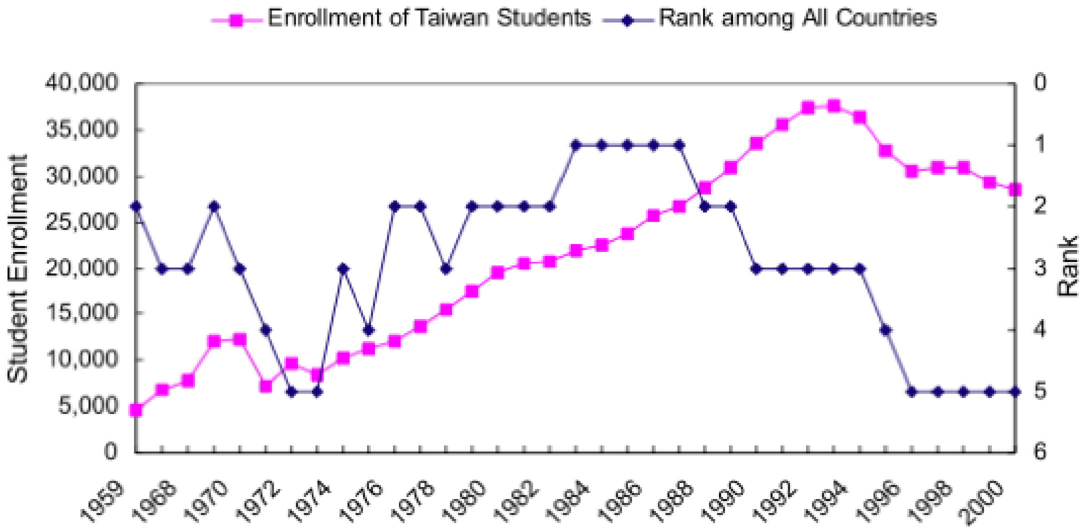

figure 3. Historical enrolment of Taiwanese students in the US (Chen & Jan, 2005)

In terms of scientific output the number of SCI and EI papers has gradually risen the previous five years before reaching 27,222 in 2005 (NSC, 2007). The impact of the papers is slightly decreasing (NSC, 2007). Compared to other countries, this number is equal to South Korea, lower than the US and Japan, but significantly higher than the CII of German papers (NSC, 2007). Nevertheless it is argued that the high quantity of papers led to a decrease in quality. Most academic publications tend to be short so that more papers can be published for promotion assessments at academic institutions. More important, for a paper to be published in overseas academic journals, domestic researchers give priority to hot research fields in foreign academia instead of focusing on the needs of local Taiwanese industries (Chu, 2003).

Concerning patents granted in the US, Taiwan has ranked fourth place (after the US, Japan and Germany) for the past five years accounting for 3.6% of all patents in 2005 (NSC, 2007). In terms of patents per capita Taiwan ranks third only after the US and Japan. However the quality of Taiwanese patents concentrated in manufacturing and process technologies is lower than others and the contribution of universities in terms of patents is low (Berger and Lester, 2005). Also, under pressure of the US the legal system concerning IPR within Taiwan has considerably improved in recent years stimulating foreign firms thinking about investing in Taiwan (Economist, 2005)

4.3.3 Government

The three most relevant departments of the government are the National Science Counsil (NSC), responsible for the research development part of S&T policy, the Ministry of Economic Affairs (MoEa) responsible for the technology development par and the Science and Technology Advisory Group (STAG) as the developer and advisor of S&T policies to the presidents office. In order to promote the semiconductor industry the government recently set up the Semiconductor Industry Promotion Office (SIPO). The policies of the Science-based Industrial Park Administration (SIPA) of the Hsinchu Sciencepark provide a good example through which practical ways government support is provided. In this section a short description and relevant functions of each department are provided.

National Science Counsil (NSC)

The NSC was established in 1959 as the highest governmental agency in promoting science and technology development. The total budget was US$ 1.265 billion in 2006. 14.7% of the budget was spent on promoting S&T in formulating, planning, coordination and evaluation mid- and long-term science and technology programs. 69.3% of the budget was spent on support for academic research by funding research projects, cultivating, recruiting and rewarding science and technology personnel, and promote science and technology interchange and cooperation. Funding is given for students to study abroad and to public institutions to hire overseas experts. 16% of the budget is allocated to the NSC's responsibility for the science parks and its administration offices (i.e. SIPA) (website NSC, 2008-11-17). The highest governing body of the NSC is the "Council Meeting," with eight to fourteen members ranging from the president of Academia Sinica, the Executive Yuan's Minister without Portfolio in charge of S&T affairs, the Minister of the Directorate-General of Budget, Accounting and Statistics, to scholars and various experts. Resolutions of the Meeting are reported to the Executive Yuan for approval and are also used as the basis for national S&T policies. Every four to five years the NSC organizes National S&T conferences attended by representatives from all different fields and backgrounds. These conferences set key goals, directions and plans for future stage S&T development. The NSC guides different government agencies as they integrate these plans into their own administrative plans. Started in 2001 the NSC holds biannual Science and Technology Strategy Planning Sessions to evaluate the results of the government's research and development efforts in order to plan strategies on technologies for several years ahead (website NSC, 2008-11-17).

Box 8. NSC initiated Industry-University cooperative research projects

To encourage collaboration between industry and universities, between 1991 and 2005 the NSC provided US$ 103.1 million to 470 cooperative research projects involving 571 firms, 2,370 researchers from these firms and 4,750 PhD and master's degree students who received training. In 2002 another project was launched, to enrich basic skills and strengthen technical research experience of involved personnel. Between 2002 and 2005 this program provided US$ 46.9 million from the NSC and US$ 20.9 million from the 4,047 involved firms training 5,735 PhD and masters degree students (website NSC, 2008-11-17).

Ministry of Economic Affairs (MOEA)

The MoEA and its Department of Industrial Technology (DoIT) have changed their policy over the years from supporting only non-profit research institutes like ITRI in performing R&D projects to directly funding projects from industry. It now supports joint R&D projects between industry and research institutes, funds incubation centres, allows industry to gain access to research institutes resources and provides matching funds for R&D projects from industry (Hsu & Chiang, 2001). A n interesting example of support to SMEs is provided in box 9.

Box 9. Small Business Innovation Research program (SBIR)

The SBIR was set up in 1999 as an initiative of the DoIT of MOEA to encourage local start-up companies pursuing innovative research of industrial technologies and products by providing matching funds. The types of research that are encouraged by the program range from improving existing technologies to developing radical new ideas and technologies. SBIR categorizes its applications into two phases. The first phase is concerned with evaluation of technical feasibility and industrial impact whereas the second phase with the implementation of the project. Between 1999 and July 2005 SBIR had awarded 1,539 research projects. The accompanying accumulated funding was US$ 101.1 million in terms of government subsidies against funds invested by the firms itself of US$ 216 million (website SBIR, 2008-11-10; website DoIT, 2008-11-10). The SBIR also provides funds with the goal of linking firms to research institutes. For example, it provided a small firm with funding to collaborate with ITRI in a joint research project (Interview with Opus, 2008). The SBIR consists of a working group which selects the research project proposals from industry to be examined by the examination committee. The examination committee exists mainly of professors from universities, since due to the issue of conflicting interests it's not possible to have industrial players in this committee (Interview with Opus, 2008)

Science and Technology Advisory Group (STAG)

Established in 1979 the STAG serves as an advisory council to the presidential office on science and technology policy. The STAG provides the premier with advise on technology policy and on policy making and budget allocation between different government departments and is involved in national human resource management which involves issues like how to attract overseas talent, adjust university programs to technology needs and how to provide best on-the-job training programs. The STAG consists of a project team and an advisory board. The role of the advisory board which consist of 13 to 17 experts from research institutes, universities and industry, is limited. They attend the two annual meetings and are available to be asked for advice at any time. The project team is located in a shared building with divisions of NSC, ITRI, III (Institute for Information Industry), MoE, and the S&T policy research and information centre. The chief of the project team is a minister of the Executive Yuan but his appointment at the STAG is full-time. Since the chief is also a minister he is in close contact with the premier. The chief and the heads of the six teams within the STAG have a monthly meeting with the premier. The project team of the STAG consists of 6 teams with a total of 50 fte's. The team's expertises are on policy design, industrial technology (which includes the semiconductor industry), ICT, Biotech, Human Resources and IT security. The members of the teams are selected out of the different research institutes such as ITRI or III. They remain under contract of their former organizations which means that the STAG does not hire and pay its employees. This gives the chief of the STAG a great amount of flexibility in HR management. The research institutes are willing to lend its employees to the STAG gaining experience in government policy and budget allocation.

The budget of the STAG is US$ 11.6 million. Additional funds are negotiable with the premier and have been allocated in the past. The budget is spent on two annual meetings and on research projects outsourced to research institutes. The two annual meetings are the Science & Technology Advisory Board Meetings and the Strategic Review Board (SRB) Meeting on electronics, information and telecommunications. 200 local and overseas experts are invited to provide suggestions on policy implementation.

The role and functioning of the STAG can be illustrated by the National System on Chip project (NSoC), initiated in 1997. The STAG project team developed the idea and related action plan while involved research institutes were asked to conduct required research. During the annual SRB meeting it invited relevant experts and discussed the need and implementation plan for the proposed NSoC program. After the SRB the chief of the STAG proposed the result to the premier who discussed it with the president. The president approved and allocated an annual US$ 47 billion to the program. The time schedule involved less than 3 years during which most time was spent on idea generation and the development of the action plan by the project team of the STAG. Once the SRB approved the plan it took only six month before budget was allocated by the president. The STAG also observes other best practices of technology policy, which includes the US, Japan, South-Korea, Singapore and the European Union (Website of STAG, 2008-11-27; Interview with STAG, 2008).

Semiconductor Industry Promotion Office (SIPO)

The SIPO was set-up under the Industrial Development Bureau (IDB) to stimulate the semiconductor industry. The office exists of 10 people with an annual budget of US$ 750,000. The office is assigned a variety of functions among which are creating incentives for investment and hold seminars to encourage industrial interaction. To achieve this it works together with other organizations (TSIA, ITRI, III, TEEMA, GSA, Digitimes, Topology). It also seeks international cooperation to gather intelligence. However due to human resources restraints it mainly focuses on serving as a coordinate window between industry and government by setting up a project website which is still under construction. A practical example of a SIPO project was the assistance of SIPO in the struggle of a local firm to place a power line to their factory through a village. SIPO arranged meetings with the local government and the firm to convince the importance and safety of the power line (Presentation of SIPO, 2008-11-11; interview with SIPO, 2008-11-11).

Hsinchu Science-based Industrial Park (HSIP)

"Clusters are geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions (i.e. Universities, standards agencies, and trade associations) in particular fields that compete but also cooperate."

Michael E. Porter, On Competition, 1996, pp. 197—198

At present there are three science parks in Taiwan. The total number of manufacturing firms in these parks reached 776 in March 2007 of which the majority is located in HSIP (website Taiwan, 2008-11-16). Since HSIP is the largest science park and contains also the largest share of semiconductor related firms the description of the function of science parks focuses on HSIP. Some facts about HSIP are provided in box 10. Based on the example of Silicon Valley in the US the first Taiwanese science park was created in 1980. However when compared to the free and open land mentality of Silicon Valley, HSIP is characterized by intense government coordination. If Silicon Valley is a natural creation, HSIP is an artificial one (Interview with SIPA, 2008). Although HSIP is now generally regarded as one of the most important success factors in the development of the semiconductor industry, its start off was less promising. In its first year 17 firms were established, against 5 in its second year and only three in its third year. It was only due to the creation of the fables business model by TSMC and the golden age of the disintegrated pc industry that pulled of the success of the science park (Interview with SIPA, 2008).

In an industrial cluster, close network cooperation and a high level of mutual dependency enables diffusion of technology, facilitates communication, cooperation and the development of new products (Hung and Yang, 2003). This is very clearly demonstrated in HSIP. Through the high density of firms a large potential for technological spillovers has been created i.e. a cluster effect (Interview with Prof. Tzeng, 2008). HSIP firms tend to interact frequently while exchanging business information, accumulating knowledge and invest in each others businesses (Lin, 2005; Chang and Hsu, 2001). Because of the vertically disintegrated semiconductor industry a high level of dependency exists among firms in different stages of the semiconductor industry (Hung & Yang, 2003).

Box 10. HSIP facts

After its establishment in 1980 the government investment has accumulated to US$ 1.679 billion on park infrastructure and facilities. 384 high-tech firms (of which 335 domestic) have settled in HSIP in a total area of 773 hectares (includes nearby Jhunan Park). Among these are UMC, TSMC and Vanguard. Five of the top ten firms in Taiwan are located in HSIP (Chang and Hsu, 2001). A total of US$ 32,233 million has been invested of which only 1.9% is provided by the government (for acquisition and development of land and construction of housing and factories (Terence Tsai and Zhou, 2006)), 9.5% by foreign funds while the biggest share, 88.6%, comes from domestic private industry. 67% of the 115,477 employees graduated from College or a higher degree of education (Dutch equivalent: HBO or higher) (website SIPA, 2008-11-10). The focus of HSIP on R&D attracted scholars and experts from abroad. At the end of 1998, 3056 returnees took positions in firms in HSIP and were responsible for the startup of 109 firms (Chang and Hsu, 2001). Through the close collaboration of industry, ITRI and NTCU/NTHU, research in HSIP is moreover demand-driven and responds to industry needs (Trappey & Chen, 2001). Firms in HSIP are increasingly geared to internationalization. Already in 1997, 58 HSIP firms had offices abroad and many international manufacturers had signed strategic technology alliances (STA) with local firms (Terence Tsai and Zhou, 2006). Up till 1997, the failure rate of firms in HSIP has been only 10%, compared to 90% to some parks in other countries (Terence Tsai and Zhou, 2006). The semiconductor industry in HSIP accounts for 164 firms (43% of total), 66,467 employees (58% of total), US$ 23,992 billion of invested capital (74% of total), US$ 22,309 billion of sales (69% of total) and showed an overall growth of 32% over 2004. In 2003 total expenditure on R&D within semiconductor related firms was US$ 935 million representing 4.2% of their total sales. 6,038 employees in these firms were R&D-related, 9.1% of total employees in these firms. The amount of patents in 2003 obtained by semiconductor firms was 1607 (website SIPA, 2008-11-10: Interview with SIPA, 2008).

The SIPA manages HSIP and is responsible for all operations. Chief of SIPA is the chairman of NSC and the SIPA itself is run by 200 employees. Most of the services can be handled online though for services requiring physical contact the SIPA provides a single-window one-stop service (Terence Tsai and Zhou, 2006). 35% of the funding is provided by NSC and 65% comes from the fee of HSIP firms which is 0.19% of their revenues. An interesting example of simplifying administration procedures by SIPA is the 'automated cargo system', which provides an integrated online import and export transaction system (Interview with SIPA, 2008).

In line with the government focus on the high-tech industry, SIPA requires firms that want to establish in HSIP to meet certain requirements. Their R&D spendings must be at least 5% of sales , employ a certain amount of domestic engineers, they must reach a certain level of R&D equipment and produce no pollution (Chang and Hsu, 2001; Interview with SIPA, 2008). To encourage investment and exports SIPA provides custom clearance, low interest loans, standard factory buildings, land without property taxes, tax-free import of machinery equipment, exemption of export taxes, and five-year tax holidays for new start-ups (Interview with SIPA, 2008). To encourage R&D, SIPA provides grants for up to US$ 152,000 (requires matching-funds) and R&D expenses may be credited against income tax to a certain limit. Import duties on R&D equipment are exempted and donation of R&D equipment is tax deductible (Chang and Hsu, 2001; Hsu & Chen, 2003). SIPA also presents awards and grants for innovative product ideas, technology development and patents application. In 2004, a total amount of US$ 3.3 was issued for this matter (website SIPA, 2008-11-10; Interview with SIPA, 2008). However, tax incentives play only a minor role in attracting firms.

Most important are the cluster effect and the proximity of NCTU, NTHU and ITRI. To stimulate human resources, government subsidises ITRI, NCTU and NTHU to train HSIP personnel (Chang and Hsu, 2001). In addition SIPA focuses on recruiting overseas experts and capital (Lin, 2005). For example, on an average of ten times a year a delegation of SIPA and related HSIP firms travel to Silicon Valley to give seminars to attract talent (Interview with SIPA, 2008).

Furthermore, SIPA allocates 1% of its budget to create an attractive living environment to attract overseas and domestic experts. This includes comfortable housing facilities and educational facilities for HSIP workers' children (Lin, 2005; Hung & Yang, 2003; Interview with SIPA, 2008). This has induced numerous Taiwanese-American engineers to return to Taiwan and work and locate themselves in Hshinchu (Hung and Yang, 2003). On the other hand, some smaller local firms sometimes prefer to locate near Taipei for living conditions (Interview with Opus, 2008).

After the example and extension of HSIP to Chunan and Tungluo, in 1995 Tainan Science-based Industrial Park (TSIP) was approved and has developed rapidly (Chang and Hsu, 2001; Presentation prof. Kang, 2004). TSIP and HSIP have both a competitive and cooperative relationship: they compete for some firms, while directing other firms to the other park if its industry is more related in the other park (Interview with SIPA, 2008). HSIP now serves as an international example to countries trying to set up science parks.

4.3.4 (Inter)national context
Taiwan is highly dependent on links with resources in other countries among which the US is most important.

Links with Silicon Valley
About one quarter of the engineers working in Silicon Valley are Asian of which 68% is Taiwanese. These experts together with the large number of Taiwanese students studying in the US, form a link with their relatives in Taiwan. Experience, capital, technology, creativity, and marketing skills are transferred to the 'hinterland' of Silicon Valley being Taiwan which has become a vital extension of the US high tech industry (Terence Tsai and Zhou, 2006).

Other International links
Taiwan is highly dependant on partnerships with overseas partners. Both industrial firms and research institutes have significant linkages with overseas partners (Interview with ITRI IEK, 2008). ITRI itself for example has an incubator centre in Silicon Valley and subsidiaries in Moscow and Germany.

Recruitment of overseas talent
To attract overseas talent to Taiwan the government assists in this by relaxing the restrictions and simplifying application procedures. A website has been set up to provide matching services for overseas talent and local recruiters (website Hire and Recruit, 2008-11-20). To assist overseas talent after they have arrived in Taiwan the government provides assistance with language problems and cultural adaptation (website IDB, 2008-11-20).

4.3.5 Interaction
One of the key characteristics of the Taiwanese semiconductor industry is its vertical disintegration and accompanied interdependence of firms. Small firms rely on each other, on large firms' orders

and on talent from universities and technology from ITRI. Formal network organizations such as the TVCA and TSIA provide regular network meetings which are also attended by government officials. The most recent TVCA meeting's opening keynote was given by current President Mah. ITRI is also a large contributor in setting up network meetings when a new technology has been developed. Most influential aspect are the informal networks in terms of interaction between universities, research institutes and firms. This is partly the result of the big influence of the Chiao Tung University as over 40% of Taiwan's IC industrial leaders are former NTCU classmates. Next, the proximity of ITRI, NTCU, NTHU and the 164 IC firms in HSIP to each other results in easy interaction processes. Industry personnel is trained by ITRI, NCTU and NTHU, industrial and ITRI leaders teach in universities, and professors of universities enjoy second appointments in advisory boards of local firms (Interview with prof. Wang, 2008; Interview with Opus, 2008; Hsu and Chen, 2003; Tzeng and Lee, 2001).

Appendix A shows a more detailed description of examples of relations between universities, research institutes, industry and government.

4.4 SWOT analysis

Based on the previous and on additional sources this section attempts a SWOT analysis.

4.4.1 Strengths

1 Complete industry with critical mass

The industry is both complete, vertically disintegrated and big in terms of number of firms and total turnover. The firms are mostly flexible SMEs and a few large IC manufacturers. It is common for customers to invest in their suppliers.

2 Successful research institute

ITRI was successfully established as an non-profit, non-governmental research institute, technology absorber and building bridge between universities, foreign technology and local industry. ITRI now serves as the initiator of advanced research projects in cooperation with industry, and still serves as an cultivator of talent.

3 Government commitment

In the past, the government has made the semiconductor industry a strategic industry to support with all resources. Both in terms of tax and financial incentives, and in terms of high-level personal relations between government officials and top industrials. For example, the prime minister personally persuaded Morris Chang (founder TSMC) to come to Taiwan.

4 Regulated Science parks

HSIP provides one-stop administration service, tax-incentives, a high quality living environment and other government sponsored incentives which made HSIP into a highly effective environment for firms to establish and attract (overseas) personnel (Ban, 2002; Interview with SIPA, 2008). Moreover HSIP creates a cluster effect between the 164 semiconductor firms, NCTU, NTHU and ITRI. The interpersonal relations, formal and informal networks and shared college and/or ITRI backgrounds of managers in firms contribute significantly to frequent interaction, cooperation and transparent information sharing among firms in HSIP (Huang, 2006).

5 Entrepreneurial climate supported by VC

The entrepreneurial climate in Taiwan is considered similar to the US (Interview with PVP, 2008). The many returning Taiwanese from the US brought the US entrepreneurial knowledge with them which further fostered entrepreneurship (Terence Tsai and Croft, 2006). But even by their culture itself Taiwanese are highly entrepreneurial preferring rather to be the head of a small firm then the tail of a large firm. The workforce is also considered flexible, adaptive and hard working (Tzeng and Lee, 2001; Yu and Chianglin, 2001). Although seed capital is harder to raise the last couple of years, venture capital for expanding businesses is abundant.

6 Linkage with Silicon Valley
Overseas students, engineers, an ITRI incubator centre and annual HR trips of SIPA to Silicon Valley create a tight relation with visible and invisible links between Taiwan and Silicon Valley. Transfer of technical and managerial knowledge makes a high contribution to the Taiwanese semiconductor industry. When engineers return to Taiwan they also bring their contacts with US firms to Taiwan.

7 Reasonable linkage between universities and industry
Over a 100 incubator centres of which the ones in Technical Universities make a very large contribution to the semiconductor industry, practical training courses, professors with second appointments, industry leaders as professors in universities, shared research projects, and moreover the fact that 40% of the engineers in HSIP are alumni of NCTU. Although some authors (Chu, 2003) argue a weak relation between academics and industry, it seems that this relation in Taiwan is stronger then in for example The Netherlands. For example, at the NTUST (polytechnic) some 100 of 300 professors are involved in technology transfer to industry (Interview with NTUST, 2008).

8 Focus on higher education
Both a cultural aspect and reflected in high government spending on education. This focus has resulted in a large pool of high educated people (Tzeng and Lee, 2001; Hu and Chiang, 2001; Saunier, 2008)

9 Taiwan-Style Profit Sharing and Stock Ownership
This has attracted local and overseas experts to enter the Taiwanese semiconductor industry.

10 High score on rate of pay and productivity
According to the Global Competitiveness Report of 2000 Taiwan was in the number two position of the world scoring higher than both Japan and the US. Also the salaries of high-skilled people although higher than averages salaries in Taiwan, are still within reasonable limits (Hung & Yang, 2003).

4.4.2 Weaknesses

11 Low internal R&D
Both large firms and SMEs conduct relatively little R&D. Instead, they rely on foreign firms and ITRI for technology development (Hung & Yang, 2003)

12 Shortage of appropriate engineers
The number of qualified graduates in Electronics Engineering from the top four universities is insufficient to supply firms other than the top IC manufacturers (Tzeng and Lee, 2001; interview with Opus, 2008; Interview with SIPO, 2008). The government policy to increase the number of universities has led to a decrease in the quality of the education level of graduates. Next to this, the focus on higher education and pressure by examination is criticized for destructing the highly needed creative minds of graduates (Hu and Chiang, 2001)

13 Short term vision of SMEs
SMEs are moreover focused on short term results and cost-reduction which also results in low R&D incentives (interview with SIPO, 2008-11-11; Interview with TTSC, 2008).

14 Dependence on foreign suppliers for equipment
Taiwan relies heavily on other countries for its IC manufacturing equipment.

15 Limited resources and domestic market size
Equal to countries like the Netherlands, Taiwan faces scarce natural resources, capacity of land restraints, and a small scale of domestic market (Chang and Hsu, 2001; Hsu & Chen, 2003; interview with SIPO 2008-11-11)

4.4.3 Opportunities

16 Improvement IPR system
Although the IPR system has improved considerably in recent years, it should be further improved to benefit foreign firms' trust to invest in Taiwan.

17 New product development and branding
Taiwanese semiconductor firms should focus on designing new products, and create branding capabilities (Chang & Trappey, 2003).

18 Mainland China (TSIA, 2002)
Taiwanese firms are shifting their low end factories to China in order to gain access to this market. As long as they keep a few high-end experimenting facilities in Taiwan this will contribute to Taiwanese high-tech industries focused on R&D instead of manufacturing (Interview with prof. Wang).

19 Slightly less independent
With respect to Taiwan's dependence on foreign suppliers for equipment Taiwan could focus on developing its own IC design software tools. This is less capital intensive than wafer and IC manufacturing equipment, and therefore appropriate for the huge amount of Taiwanese SMEs in IC Design (Hung & Yang, 2003).

20 Stock-options system is changing
Due to a recent changed accounting law it is now less attractive for firms to offer stock options to new employees. Therefore a trend is spotted that engineers no longer solely choose for the firm with the highest stock options offering but also consider the pay of normal salary and job contents. This might result in engineers preferring careers in SMEs instead of the few large firms (Interview with Digitimes, 2008).

4.4.4 Threats

21 Scarceness of experienced engineers in electronic engineering (Terence Tsai and Zhou, 2006)
Both the quantity and quality of Taiwan human resources has to be increased, especially to serve the growing IC fables industry (Hung & Yang, 2003). Due to the increased amount of universities and improved living conditions in Taiwan fewer students feel the need to study abroad. As a result they lack the foreign experience which was a key success factor in the development of the semiconductor industry.

22 IC manufacturing facilities moving offshore (Terence Tsai and Zhou, 2006)
In 2002, half of Taiwan's electronic production was off the island. In terms of employment levels this is seen as a threat.

23 Increasing global competition
On the lower end of the value chain the opening up of Mainland China to foreign investment in 1979 and membership of the WTO compose a threat to some while an opportunity, in terms of complementary industries of Taiwan and Mainland China, to others. Incentives, tax holidays, an abundant supply of land and engineering talent (with many students in the US) are offered by science parks in Beijing, Shanghai and Shenzhen. Next to this, access to Mainland China's market is one of the main reasons to invest in the Mainland (Berger and Lester, 2005). On the high end of the value chain, Taiwan competes with the USA, Japan, and South-Korea. Additionally Taiwan faces also increasing competition from Singapore, Hong Kong, India and other upcoming South-East Asian countries (Terence Tsai and Croft, 2006).

24 Bad reputation in building own brands (Berger and Lester, 2005)
Brand building requires thorough knowledge of the market. Although in the IT industry a limited number of successful examples exist (Acer, Asus, HTC and Visio) some argue that Taiwan as an isolated island is too distant from the US and European market to acquire enough understanding

to build successful brands for western markets (Berger and Lester, 2005). Also the lack of after-sales-support provided by Taiwanese companies is a major concern in building up a brand (Interview with Digitimes, 2008).

25 Increasing cost of labour forces and scarcity of land (Hsu & Chiang, 2000; Terence Tsai and Zhou, 2006)

4.5 Success factors

The development of the Taiwanese semiconductor industry is the result of a number of factors which have turned to be successful. In this section an effort is made to identify those success factors, categorized in factors which were typical for Taiwan and not easy to be copied to other countries (context-related) and factors that might be considered as input to other countries' policies (copy-able).

4.5.1 Context-related

1 Correct early choice of industry development direction
When most of the world still regarded Taiwan as a cheap factory for making toys, the policy direction was set out to develop a high-tech semiconductor industry. This turned out to be the right choice at the right moment.

2 Successful acquisition of foreign technology
By sending engineers to RCA for training and acquiring the CMOS technology, ITRI successfully mastered this technology which was spun off in the first ITRI-spin off UMC.

3 Visionary leaders make the difference
Wen-Yuen Pan advised the Taiwanese government that the semiconductor industry was the most suitable industry to support for Taiwan. He set up a goal to develop this industry and created the ERSO in 1974. Furthermore, he selected Taiwanese experts to learn the technology at RCA and transfer it to Taiwan in 1976 (Ban, 2002). Other examples are Morris Chang (ITRI, TSMC) and Robert Tsao (UMC).

4 Belief in higher education
The cultural related believe in higher education was one of the success factors in the development of the semiconductor industry since it resulted in an abundance of well educated and well trained pool of engineers and professionals.

5 Tax incentives are inevitable
Tax incentives are necessary to keep domestic high-tech companies within the Taiwanese borders. Though, in comparison to Singapore and Mainland China, tax incentives in Taiwan are less attractive (Chang and Hsu, 2001).

4.5.2 Copy-able?

7 Recruitment of overseas talent
Taiwan aggressively recruited overseas Taiwanese engineers in the US to return to Taiwan who brought in technical abilities and market expertise that lifted the Taiwanese semiconductor industry (Chang and Hsu, 2001; Interview with Prof. Kang, 2008; Yu and ChiangLin, 2001). Government-led overseas recruitment trips, can stimulate overseas talent to enter the local industry. An example is the trips that the SIPA organizes to promote HSIP in Silicon Valley, on a regular basis.

8 Set up of advisory group with autonomy and power
The STAG develops science and technology policy, consults experts from all kinds of fields in the annual meetings and is headed by a full-time minister of the Executive Yuan who has close connections to the premier.

9 Government-regulated science parks
Extensive support by a science park administration office (SIPA) to smoothen interaction between firms and between firms and the government with practical instruments such as the automatic customs clearance for exports, smoothens the operations of science park inhabitants. Moreover, HSIP was set up in Hsinchu to create a close proximity between universities, research Institutes and industry. The cluster effect is one of its main key success factors.

10 Focus on research institutes
The emphasis of the government's strategy in developing the semiconductor industry lay on supporting research institutes in developing technology and transfer it to industry (Lin, 2005; Hsu and Chiang, 2001). This is different from other countries like the US, South Korea, and Singapore where businesses and universities define the national innovation system (Lin, 2005).

11 Continuous training
Fast changing semiconductor technology requires continues training in which government sponsored trainings institutes can play a crucial role.

12 Second appointments
Professors in universities and CEOs in firms with second appointments in each others organizations stimulate the exchange of knowledge and interaction

4.6 Current and future government policy

In this section, the current response of governmental policy is described to the current challenges facing the Taiwanese semiconductor industry.

As the semiconductor industry has built up its capacity and is able to seek global technology resources for further development, the government's role gradually fades. Nowadays the government plays a supportive (facilitator) role rather than leadership role. To sum up the most recent challenges which are faced by the Taiwanese semiconductor industry, these are: (1) rapidly catching-up of emerging economies and relocation of ICT manufacturing industries; (2) technology-related manpower shortage; (3) insufficient R&D capacity; (4) high dependency on foreign supply of high-grade materials and equipments.

To respond to these challenges, the Taiwanese government has coined out some policies to improve the business environment for semiconductor industry. Overall, the policies have two distinctive perspectives, one is to enhancing innovation system's performance and the other is to further technology development.

4.6.1 Enhancing Innovation system perspective

Global network and linkage、expanding industry's knowledge base
Quick absorbing foreign knowledge and transforming it to business has always been Taiwanese entrepreneur's strength. As the pace of globalization quickened, adopting an open innovation model and global sourcing will be the industrial policy's focal points. The future development of Taiwan's semiconductor industry must place its efforts on global user's perspective and leverage global knowledge sources. Hence, the industrial policy will promote and encourage R&D collaboration domestically and globally, such as funding the projects and participation on FP7. Also, it is the government's policy to induce foreign investment and encouraging establishment of labs and R&D centres in Taiwan by giving excellent terms.

Enhance network for innovation system players
A domestic knowledge source is also crucial to the Taiwanese semiconductor industry. However, simply put, the innovation system players lack interaction due to different agendas and motivations. This hinders overall knowledge generation process. Some bilateral collaboration activities between industry-academia and industry-research institutes have been observed, but it is still insufficient to form a strong supporting force for the semiconductor industry. Thus, the government's policy strongly supports networks and collaboration between innovation system players by funding industrial technology development programs and SBIR.

Linking the clusters
Based on the successful clustering experience of the Hsinchu science park, the Taiwanese government is active on building up knowledge intensive industrial clusters in the southern Taiwan Science Park and mid-Taiwan science park. These high-tech clusters will form a so call 'west Taiwan innovation corridor.' In supporting cluster's development, the government will further invest on infrastructures including broadband wireless telecommunication, roads, utilities, regional business incubation centres, technology transfer centres, etc. It is also worth mentioning that the Taiwan High Speed Rail that serves to link the west Taiwan innovation corridor, increases mobility between the clusters.

Technology talents cultivation
Human resource is a high priority for industrial policy makers. In addition to university's education for basic knowledge in the semiconductor field, the Semiconductor Academy was founded in 2002 for technology talents cultivation purpose. The academy offers advanced professional courses and training for industrial talents in IC design, semiconductor manufacturing, IC package and testing. The academy further collaborates with National Science and Technology Program for System on Chip (SOC) and National Nanoscience and Nanotechnology Program in order to prepare the students for next generation technologies.

4.6.2 Technology development perspective

Achieving economy of scale
About 70% of global semiconductor manufacturing capacity is located in the west Pacific region. Taiwan has an excellent geo-economical position in the east pacific region; hence, the Taiwanese government would further leverage this advantage to serve as a semiconductor R&D and manufacturing hub based on Taiwan's complete semiconductor industry chain. Consequently, a stress on quality, costs reduction and achieving an economy of scale are key success factors for future market competition. Since building 12" fabs and R&D on advanced fabrication processes are important strategies for advancing Taiwan's semiconductor industry's competitiveness, the government's policy is to encourage firms to upgrade current technology and expand their scale by offering tax breaks. Up to the first quarter in 2008, there are 17 12" fabs in production, accounting for one-third of global wafer fabrication capacity.

Enhancing technology capabilities through national technology development programs
The Taiwanese policy goal is to become the global System-on-Chip design and manufacturing centre by 2015. The government funds national technology programs to facilitate the building up next generation technology capabilities on next generation memory chips, 3-Dimensional stacked IC (3D IC) and SoCs. Two national programs are devoted to that mission: National Science and technology program for SOC and National Nanoscience and Nanotechnology Program. The purposes of these programs are to build up common technology platform, establish strong Silicon Intellectual Properties (SIP), integrated electronic design automation (EDA), and to provide better IC designing environment. Currently the programs are carried out by academia and research institutes and it will expand for industrial participation.

Achieving greater autonomy on materials and equipments
As stated before, Taiwan's semiconductor industry is characterized by a high dependence on suppliers of equipments and materials. According to the Industrial Development Bureau (IDB) of the Ministry of Economic Affairs (MoEA), the overall self sufficient rate on equipments and materials is less than 15%. It thus restricts Taiwanese firms' bargaining power, and creates an imbalance of development in the semiconductor industry. Therefore, the government has put great attention on this issue. The government will coordinate several funding agencies such as the NSC, IDB and DoIT to initiate joint task forces including academia, research institutes and firms for collaborative research on semiconductor manufacturing equipments and materials. The policy target is to achieve front-end equipment autonomy from current 5% to 20% by 2012, rear-end equipment from current 25% to 60%, and parts/components from current 20% to 80%.

4.6.3 Outlook

Despite the fact that the global economy has been hit by a financial crisis that originates from sub-prime issues in the U.S., consequently, the projection for the Taiwanese 2009 economy performance is not very promising. Taiwan's semiconductor industry is known for its agile adjustment capability, hence, despite some mergers and acquisitions will happen in the middle and lower industry chain, such as in DRAM manufacturing firms, it is expected that most of the firms will swiftly adjust to the economic hardship. In addition, as most of the world's big IDMs have transformed to fab-lite or fables businesses, Taiwan's foundry businesses would benefit from the increasing IC OEM orders.

To extend Taiwan's technology capabilities in semiconductor applications, the industry-research institute-academia consortia has already started researching the next generation memory chips (for example, PCM and MRAM), and is very active in integrating sub-industries such as materials, equipment, EDA tools, IC design, manufacturing, package and testing. The consortia also puts a lot of efforts in SoC and 3D IC standard making and building up platforms for developing new product applications. So, the linkage and collaboration between academia, research institutes and industry will further develop to a mature stage in the next few years to come.

On the market side, emerging economies such as China, India and Vietnam could be the next wave of semiconductor industry value chain extension due to their high economic growth rate and high demand for consumer electronics. Since China has the biggest consumer market in the world, certainly China will play a key role in the global semiconductor supply chain. With its enormous talent pool, China is very suitable for developing a fables IC design industry. As to manufacturing, Taiwan has already established strong capacity and technology capability, therefore, there should be room for further collaboration between Taiwan and China. The government has point out that in next few years the authority will focus on policy deregulation for technology exportation. Some certain technology items will be open for strategic deployment in China.

Semiconductor industry business model transformation
The important movement is business model innovation, that is, to migrate from just an OEM model to a services and production model. As the industrial leader, TSMC, has announced, business model innovation will be the next stage of development for Taiwan's semiconductor industry. Aside from manufacturing, TSMC is aiming to provide customer integrated services. TSMC has rolled out a so called "open innovation platform" that allows TSMC to collaborate with its customer on early stage IC designing. As an open innovation platform provider, TSMC will integrate IC designing tools such as EDAs, SIPs, and TSMC's own fabrication technologies to construct a Design & Technology Platform (DTP). The platform is expected to speed up and consolidate IC design stage for customer's needs, also it will reduce costs for customers. This movement will certainly set a new paradigm for the rest of the industry to follow.

5 Innovation policy in the Dutch semiconductor industry

In order for the reader to put the Taiwanese case in perspective, this section provides a description of national governmental policy towards the Dutch semiconductor industry.

5.1 National innovation policy context

The innovation system of the Netherlands is a complex system with many actors and relations. The two main ministries responsible for designing innovation policy in the Netherlands are the Ministry of Economic Affairs (EZ) for technology and innovation policy and the Ministry of Education, Culture and Science (OCW) for science and research policy. The Ministry of Agriculture, Nature and Food quality (LNV), the Ministry of Spatial Planning, Housing and Environment (VROM) and the Ministry of Transport, Public Works and Water Management (V&W) also have an interest in innovation policy on their specific fields.

Innovation policy in the Netherlands has always been a combination of generic and specific policy. While the innovation policy mix became more generic in the period 1995-2005, recently it has become more specific with the introduction of the notion of "backing winners" – both in "key areas" and in regional "peaks". As a relatively small country, similar to Taiwan, the Netherlands cannot excel in every domain, which translated into an innovation policy in which the creation of focus and critical mass became a major policy objective. The focus on specific themes or areas, with the aim to create international excellence in those themes, was a new feature in Dutch innovation policy.

Programmatic approach and development of innovation programmes
The new programmatic approach was introduced as part of a major streamlining of the innovation policy mix in 2005. Since then, the innovation policy mix consist of a basic package with generic instruments that help (innovative) entrepreneurs with information, advice and capital and a programmatic package with specific instruments, i.e. innovation programmes for a limited number of prioritized areas that have strategic importance for the Dutch economy and in which industry can achieve global excellence. These so-called "key area's to the Dutch economy" ("sleutelgebieden") were identified in 2004 by the Innovation Platform and were later adopted (and broadened) by the Ministry of Economic Affairs (EZ) to qualify for support from the programmatic package, and include the following areas: Flowers & Food, High Tech Systems & Materials, Water, Creative Industry, Chemicals Industry, Pensions and Social Insurance, and Life Sciences.

In these "key areas", EZ invites industry and research institutes (or stakeholders themselves take the initiative to develop am innovation programme and present it to EZ) to take the lead and develop a shared vision and strategic (research) agenda in a certain area. An external strategic advisory committee advises the Minister of Economic Affairs in selecting those initiatives that are most promising. After selection a full fletch innovation programme is developed. The initiators themselves play an active and leading role in the design of the programme (i.e. defining the main portfolio of instruments, contents of the programme). EZ and the funding agency SenterNovem are only partially involved and play a role as facilitator (i.e. bringing together stakeholders, involving SMEs).

The initiators also determine the most suitable form of organisation and what action is needed to reach the objectives. In the programme-based approach a broad range of actions can be taken and it is much broader than R&D support alone. Topics to be addressed in an innovation programme may include reducing unnecessary regulations, financial support for R&D, facilitating networking, promoting start-up firms or stimulating export of Dutch technology. As a result each programme is unique, applies different policy instruments, and tailored to the specific needs of a certain (business) area. This means also that the innovation programmes rely on the organizational skills and (financial) commitment of the field.

When the programme is finished it is again reviewed by the strategic advisory committee and finally the Minister decides whether to fund the programme or not. During the execution of the programme the consortium holds the ownership of the programmes, a representative of SenterNovem is safeguarding the government perspective.

5.2 The first innovation programme: Point-One

The innovation programme Point-One (P1)(see box in the field of nano-and microelectronics and embedded systems was the first of this new type of innovation programmes in the Netherlands.

Box 11. The Point-One association
The Point-One Association was established by a group of founding fathers, with representatives from the four main interest groups in the R&D ecosystem, i.e., SME, knowledge institutes (universities and research organizations), mid-size industry (annual revenue below €500M), and large industry. All industrial and academic R&D actors and ecosystem stakeholders within the scope of the Point-One innovation program have been invited to become a member. Within one month after the Association was established, more than 100 partners have applied for membership. To manage and supervise the program, Point-One installed an Executive Board and Program Council. The present governance structure consists a.o. of dedicated working groups for the planned R&D and ecosystem evolution activities, a program office for communications, branding, call and project support, and overall program operations for its members. An Academic Council from key academic partners advises on scientific matters.

The multinational firms Philips, NXP and ASML are main consortium partners and together with a number of research organizations the main initiators of the innovation programme. It started in June 2006 as a pilot programme. Government support is about 50 million euro for the 2006-2009 period. In 2008 the programme was developed further and extended into the domain of mechatronics and robotics. Point-One Phase2 is funded by EZ with 153 million euro for the 2009-2012 period. The private sector contributes at least the same amount to the programme.

The ambition of the Point-One innovation programme is to establish an innovation cluster of collaborating companies and knowledge institutes in the areas of nanoelectronics and embedded systems. The Netherlands should become a world leader in these areas with a reputation comparable to that of Silicon Valley. More specifically, Point-One aims to realise an annual increase in turnover of 5% and eight high-quality start-ups. In addition, Point-One intends to embed and anchor participants, especially SMEs in international collaborative networks. It aims also to grow stronger by close collaboration with Euregional knowledge clusters in Aachen (Germany) and Leuven (Belgium) and the industrial clusters in Crolles (France) and Dresden (Germany). The ambition is to make Point-One an effective part of a European network of 'R&D-ecosystems' that mutually complement and reinforce each other.
Point-One works along four strands:

Strategic research initiatives
Strategic collaborative research projects on nanoelectronics and embedded systems, as a Dutch contribution to the European Research Agendas ENIAC (nanoelectronics) and ARTEMIS (Embedded Systems). The Dutch contributions to the MEDEA+ and ITEA2 are an active link from Point-One to European R&D consortia. Activities include two big platform projects (Memsland and OML) in the field of nanoelectronics, an international call for participation in Eureka and open calls for proposals for R&D and feasibility studies in the area of (mainly) embedded systems.

Open innovation institutes
Point-One aims to work actively tuned to the business plans of two other research institutes in the field in the Netherlands, i.e., the Embedded Systems Institute (ESI) and the Holst Centre, thereby creating an open interface within industry and between industry and academia while aligning industrial needs with academic technology feed-in.

Knowledge interaction between academia and industry
Aims to align academic and polytechnical curricula with industry and meet industrial needs in terms of skilled people and level of training. Activities include the development of an Human Capital roadmap and stimulating students to study subjects in nanoelectronics and embedded systems.

SME development
SMEs are an essential fibre in the Point-One fabric. Point-One aims to actively support existing SMEs and start-ups and to improve SME global competitive positioning in relevant technologies. Point-One has developed an SME radar screen and capabilities definition, an SME quality improvement program (QLTC) and created a Venture Capital Fund. Moreover, SMEs are specifically targeted in the Open Call for R&D projects (website Point-One, 2008).

Since the start of the Point-One innovation programme, seven other innovation programmes are launched in the Netherlands in different areas including Food & Nutrition Delta, innovation programme Water technology and offshore technology (maritime), High Tech Automotive systems, Life Sciences & Health, Chemical innovation programme (including polymers innovation programme) and Materials innovation programme (M2i). For the period 2005-2012 a total policy budget of 846 million euro is reserved for these eight innovation programmes .

Way of working: the roadmap of Point-One
The program is guided by a Multi-annual Roadmap, an Emerging Technology Agenda, and Annual Plans for each consecutive year, managed through an open and transparent governance model.
The first version of the Multi-annual Roadmap (MRM) was finalized in an intense process of open consultation with the field, in which all experts from stakeholders were involved, being large industry and innovative SME, key institutes and universities, as well as the Dutch authorities. Leading elements in the MRM are business cases, highlighting market relevance, benefits for the Dutch economy, and application & technology challenges in each of the five Point-One target areas. In this way, a coherent set of value propositions is build up from integral exploitation of nanoelectronics, embedded systems, and mechatronics technology insights.

The 3-5 year implementation scope of the industry-driven and academia-approved business cases is complemented with the 5-15 year outlook of the academia-driven and industry-approved Emerging Technology Agenda (ETA). While the business cases are based on market pull, the ETA starts from technology push. But in both, a connection is made between the technical challenges and (potential) applications in Dutch high-tech products and services.

The top-line priorities of Point-One are closely linked with the international R&D roadmaps in the EUREKA clusters and the European JTIs. Point-One will regularly interact with these organizations and with leading European competence clusters in the Point-One domain, in close cooperation with the Dutch authorities. Through these interactions, continuous alignment is maintained in terms of technical and business content as well as in policies for stimulating the ecosystem, such as SME participation and leveraging knowledge infrastructures.

5.3 Point-One from a government perspective: measuring performance and impact

Because the ministry of Economic Affairs (EZ) and its innovation agency SenterNovem are not in the driving seat themselves during design and execution of the programmes, an elaborate indicator-based monitoring system is essential for EZ/SenterNovem to be able to keep a finger on the pulse. Indeed, a precondition for success of the whole new programmatic approach of EZ is demonstrating the effects of public support for industrial R&D and innovation and, more broadly, the contribution of the innovation programmes to policy objectives. Proper monitoring and evaluation are key to demonstrate this. Therefore, the initiating consortium together with SenterNovem needed to develop an indicator-based monitoring and evaluation methodology at the start of the innovation programme Point-One. As Point-One was the first of a series of innovation programmes in the Netherlands, the methodology was not yet clear and needed further development and tuning. Technopolis Group was asked to conduct a "baseline study" in order to develop this monitoring and evaluation methodology (i.e. defining and measuring indicators and assessing the overall performance of the Point-One eco-system) and take a "snapshot" of the current situation that can be used as reference situation for future monitoring and evaluation.

These first experiences with Point-One show that the new programmatic approach was a learning process for all parties involved. And the development of a monitoring and evaluation system was also part of it. Indeed, as it turned out, the baseline study conducted by Technopolis Group played a constructive role in aligning mutual expectations and clarifying the division of labour . The methodology developed for Point-One is now used for the other innovation programmes as well. Rijswijk et al. (2008) described experiences with the first innovation programme Point-One from an government perspective in more detail. It appears that the industry was indeed in the lead during the agenda-setting phase. The role of the government was limited to involving new partners (in particular SMEs), deliver information and facilitate the process if needed. Also during the action-planning phase, industry was mainly responsible in developing the innovation programme. The division of roles between the government and the Point-One consortium was much more complicated than with conventional (top-down) innovation programmes. Indeed, based on the experiences with Point-One, Rijswijk et al. suggest that the government should be more actively involved in the implementation phase and have a final say in determining which government interventions will be put in place. With regard to the division of roles and responsibilities between industry and government, it is argued that the programme implementation and execution should be laid down in a clear governance structure for the programme. The programme needs to be owned by industry, but the government has to have a say in the allocation of public funds to, for instance, R&D projects.

6 Conclusion

In analysing the development of the innovation system with respect to the Taiwanese semiconductor industry, the main conclusion is that the government has played a leading role in the start-up phase of the semiconductor industry. It started with the early policy choice of the semiconductor industry as the strategic industry to support with all means. Since then the government has overcome a major lag in technology with developed countries by setting up a non-governmental research institute aimed at acquiring foreign technology and develop it internally. This resulted in the acquirement of CMOS technology from the US firm RCA in the 1970s. Next to technology acquirement, the government realised that a high-tech industry required high-educated engineers preferably with overseas experience. As a response, it promoted science and technology studies and funded Taiwanese students to study in the US. Although only a small percentage of these students returned to Taiwan, these returnees brought back all the skills needed to develop the semiconductor industry. The government realised that the research results within ITRI should be spun off into private firms. To foster this, it set up a supportive Science-based Industrial Park in close distance of its two main technical universities and ITRI. The first firm to be established in 1981 was the spinoff of the through RCA acquired CMOS technology: UMC. After that, government officials convinced the experienced entrepreneur Morris Chang to become the president of ITRI, and gave the objective to create another spinoff to boost the semiconductor industry. Morris Chang developed the foundry business model, convinced the government that it would create a market of fables design houses, and started TSMC in 1987. As Morris Chang projected, after that an investment boom of fables design houses took off in the nineties. Clearly, the government has played a major role in the development of the Taiwanese semiconductor industry. Context-related success factors are the cultural related emphasis on higher education and the characteristically hard working, in the early days relatively cheap, Taiwanese labour force.

Nowadays, the government takes on a more facilitating role as the semiconductor industry reaches maturity. It focuses on the one hand on enhancing its innovation system, by adopting an open innovation system and building (global) networks. With the shortage of appropriate engineers, it seeks ways to improve the number and quality of its engineers by setting up specific training institutes and attracting overseas talent. On the other hand, it focuses on developing its technology base through national technology development programs, achieving a greater autonomy of equipment, and further increase economies of scale. With respect to the mainland China, the Taiwanese government is realising this opportunity and is already deregulating its policies.

7 Discussion

This study has made an effort in identifying the relevant organisations and events that have shaped the Taiwanese innovation system with respect to its semiconductor industry. The goal of this study is to identify the success factors that made a difference in this process, to learn whether these can function as policy input for other countries. To put the Taiwanese case in perspective, co-writing partners of Technopolis and Point-One have provided a description of Dutch innovation policies with respect to the Dutch semiconductor industry.

Since this study, compared to most scientific studies, does not focuses on one or two relations between a few subsystems but instead, focuses on the whole innovation system, the difficulty lies in the balance between describing relations in-depth and creating a more general overview. Due to time restraints, limited information and a language barrier in some cases, a balance between the two was strived for.

This study does also not involve a comparison between the Taiwanese and the Dutch case, since this can only be made when thorough knowledge of both cases is achieved first. With respect to this study, a more thorough analysis of the Dutch case should be considered first.

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Appendix. Brief description of relations between different subsets of Taiwanese IS

Universities ←→ Industry
Universities are the suppliers of talent to industry. At present, at least 40 percent of Taiwan's IC industrial leaders are alumni of NCTU (Chang & Hsu, 2001). With respect to the supply of talent nowadays, firms complain having trouble in recruiting qualified graduates from other universities than the top 4 (interview with SIPO, 2008-11-11, Interview with ITRI IEK, 2008). The linkage between technical universities and industry is stronger than between normal universities and industry. For example, at the NTUST, around 100 out of 300 professors are involved with industry. Professors at universities sometimes have a second appointment in advisory boards of industries, and alumni of universities who are now in industry, assist universities in examination (Interview with prof. Wang, 2008, Interview with Opus, 2008). Famous entrepreneurs are involved in giving lectures and providing donations to the top universities. For example, Morris Chang (TSMC) and Stan Shih (Acer) give lectures which are very popular and Morris Chang even prepares all his material himself and rehearses his lectures with the management team of TSMC (Tzeng and Lee, 2001). Robert Tsao (UMC) as an alumni of NTHU, donated US$ 500,000 to his former university after playing a game of chess with the president of NTHU. The other way around, employees of HSIP firms attend classes at NCTU and NTHU (Hsu and Chen, 2003). As a result of government funding for incubation centres within universities, over a 100 universities now have an incubation centre. The results vary. NTCU and NTHU spun off 15 firms in 1999, but the contribution of some other universities' incubation centres is much less. Though, in terms of direct contribution of universities to the R&D projects within industry, some authors argue that also in Taiwan, this has been limited (Jan & Chen, 2006).

Research Institutes ←→Industry
Research institutes interact with industry via development of technology and then the transfer of technology and human resources, joint research programs, technical assistance and training of personnel (Hsu and Chen, 2003). ITRI is the most important research institute with respect to the linkage to industry, via joint research projects, seminars, the incubator centre and related spinoffs. For example, the small firm Opus has a monthly meeting with the Material Research Lab within ITRI (Interview with Opus, 2008).

Industry ←→ industry
Because of the vertical disintegration, and the high density of firms in the science parks with the resulting cluster effect, the interaction between industrial firms is high. Firms are organised by the TSIA and TVCA. TVCA provides network activities such as the 'Taiwan Venture Forum and matchmaking Showcase', sponsored by the government (DoI) in which even the president of Taiwan contributes in giving a keynote. Foreign firms establishing subsidiaries in Taiwan also made their contribution to the local industry, both in terms of acting as high demanding customers to it's local supplier, as in recruiting local talent. These local engineers acquired both technical and managerial knowledge after which some of them started up their own firms which became suppliers of the foreign firms (Interview with Ben, 2008).

Government → Research Institutes
For example, the STAG asks ITRI IEK to conduct research on how which technology policy to implement with respect to the DRAM industry. Next to ITRI, the STAG also sources out projects to TIER, III and STPC (Interview with STAG, 2008; Interview with ITRI IEK, 2008).

Research Institutes ←→ Universities
MOEA channels results from basis research to research institutes

ITRI IEK visits professors in the top 4 universities once a month, moreover to share thoughts on methodology (Interview with ITRI IEK, 2008). Prominent ITRI figures teach classes at top universities. For example, former ITRI director Chintay Shih shared his experience to fully-packed classrooms at NCTU. On the other hand, ITRI researchers from all levels attend classes at NTCU and NTHU (Tzeng and Lee, 2001).

Universities ←→ Universities

Focusing on the relation between NTCU and NTHU, it shows both a competitive aspect in terms of recruiting students and acquiring funding, and cooperative aspect in terms of sharing teaching and research resources.

Government ←→ Industry
Industry is involved in the annual science and technology meetings, and the government provides matching funds for R&D projects (Hsu and Chen, 2003).