The role of public policy in the formation of a business network

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Ying Shih*

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*Research Fellow at the Centre for East and South-East Asian Studies, Lund University,
tommy.shih@ace.lu.se

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Abstract

To promote industrial development and economic growth is a vital issue for governments all over the world. The ideals guiding policymakers in their endeavours, strongly influenced by traditional economics and the innovation system approach, are that innovations based on new and advanced knowledge are central for industrial and economic development. As is exemplified through the quote below policymakers have no problem with finding inspiration from regions such as Silicon Valley.

> The idea that so much could grow in so short time within such small geographical area sent planning bodies from Albuquerque to Zimbabwe scrambling to grow the next Silicon Valley on their own backyard. Sturgeon (2000: p.15)

But although the identified "generic" features have been copied, there are few examples of how ambitions to "artificially" create policy supported high-tech based business networks and industries have succeeded. One of the few successful examples of policy created high-tech industries often mentioned is the Taiwanese semiconductor industry. The story of the Taiwanese semiconductor industry is impressive as the one of Silicon Valley; in just a few decades a booming industry developed from scratch. One of the most common explanations to the transformation addresses the governing role of the state in coordinating industrial development and creating a successful semiconductor business network. Some of the major factors mentioned were for example the creation of public research institutes, the public provision of R&D, and the subsequent transfer of technologies to a downstream sector created by Taiwanese policy. This envisioned development scenario has been strongly supported in Taiwanese policy circles and forms a foundation of contemporary Taiwanese industrial development policy. However this model of business creation applied to other industrial areas has been widely criticized for not fulfilling it promises.

To investigate this issue, this paper takes a different and complementary view of the emergence of a Taiwanese semiconductor business network. Based on a resource interaction perspective the study aims to increase the understanding of forced network creations. The findings argue that the understanding that a network was created by policy is clearly an over-simplification which omits several important factors in the emergence of the semiconductor business network.

Contents

Introduction

The promotion of industrial development and economic growth is a vital issue for governments all over the world. The ideal that guides policymakers in their endeavours, strongly influenced by traditional economics and the innovation system approach, is that innovations based on new and advanced knowledge are central for industrial and economic development (OECD, 1996; Eklund, 2007). This observation is explained by the OECD (2007: p5):

> Today, innovation performance is a crucial determinant of competitiveness and national progress. Moreover, innovation is important to help address global challenges, such as climate change and sustainable development. But despite the importance of innovation, many OECD countries face difficulties in strengthening performance in this area. […] Governments can also play a more direct role in fostering innovation. Public investment in science and basic research can play an important role in developing ICT and other general-purpose technologies and, hence, in enabling further innovation. This highlights the importance of reforming the management and funding of public investment in science and research, as well as public support to innovative activity in the private sector.

To support development of advanced knowledge and to create a system that facilitates the transfer of the results from research to industry has consequently been a main concern in contemporary policymaking. However, empirical evidence suggests that commercializing knowledge is a cumbersome task with few traces of linearity. That it is not that easy to support artificially the development of new high-tech solutions which will lead to knowledge-based industries and business clusters has been experienced by many governments. An editorial in *The Economist* (2007: p4) gave the following opinion on this experience:

> EU officials, like government bureaucrats everywhere, are obsessed with creating geographic clusters like Silicon Valley. The French have poured billions into *pôles de compétitivité*; and Singapore, Dubai and others are doing much the same. There are dozens of aspiring clusters worldwide, nicknamed Silicon Fen, Silicon Fjord, Silicon Alley and Silicon Bog. Typically governments pick a promising part of their country, ideally one that has a big university nearby, and provide a pot of money that is meant to kick-start entrepreneurship under the guiding hand of benevolent bureaucrats. It has been an abysmal failure.

Despite these disappointing results there are examples of high-tech business networks and industries that are presented as successful creations of policy. A salient example is the Taiwanese semiconductor industry based in Hsinchu. The development of this industry is intimately linked with Taiwan's economic success. In just a few decades, the Taiwanese economy transformed itself from being dependent on agriculture to become one of Asia's high-tech centres. In short the story commonly told is that in the early 1970s Taiwan was a backwater economy. The country was dependent on agricultural production and labour-intensive manufacturing of textiles, electronic components and plastics. At that time, Taiwanese policymakers decided that it was time to direct industrial production towards more knowledge-intensive sectors and move up a step on the economic development ladder. A field that was identified by the government as a future industry which would allow Taiwan to take this development leap was semiconductors. Public policies were implemented to speed up development in a hitherto non-existent semiconductor industry. The focus on semiconductors turned out to be beneficial for the Taiwanese economy. Since the 1980s the economic growth of Taiwan has been closely associated with the development of the semiconductor industry located in Hsinchu, also known as the Silicon Valley of Taiwan. Two decades after the emergence of the first few semiconductor businesses in the early 1980s, the Taiwanese semiconductor industry was ranked the fourth largest in the world[1] and consisted of nearly 400 companies[2]. At the end of 2005 the Taiwan Semiconductor Industry Association (TSIA) estimated that 60 per cent of worldwide semiconductor foundry, package and testing revenue, 25 per cent of worldwide semiconductor design revenue and 25 per cent of worldwide DRAM revenue were generated by Taiwanese companies. The total economic value generated by the Taiwanese semiconductor industry totalled 1118 billion New Taiwan Dollars (roughly 33 billion USD) at the end of 2005 (TSIA, 2007).

Regardless from what vantage point the development of the semiconductor industry and the Hsinchu region is viewed, it appears impressive. Within a few decades, a new industry and a flourishing business network resting on high-tech and innovation emerged in a country which had previously relied on traditional industries and small and medium-sized companies with weak R&D capacity. The most common interpretation of the Taiwanese semiconductor development is that it was a result of public policy engagement

[1] Defined in terms of production value, surpassed only by the USA, Japan and Korea.

[2] The companies can be classified as: 268 IC design houses, 6 wafer suppliers, 4 mask makers, 13 fabrication companies (fabs), 33 packaging houses, 35 testing houses, 15 substrate suppliers and 19 chemical suppliers (TSIA, 2006).

in coordinating industrial development (see, e.g., Liu, 1993; Mathews & Cho, 2000), a view which is also heavily stressed by Taiwanese public policy (MOEA, 2003). Hence the picture of a dynamic semiconductor business network created in the hands of foreseeing government bureaucrats has come to serve as an important role-model for how to create new industries in Taiwan (Liu, 1993). As has been interpreted by e.g. Liu (1993) or Chang et al., (1994) the main policy measures undertaken were aimed at the foundation of research institutes, a public provision of R&D, the subsequent diffusion of the research results to the private sector, and the establishment of science-based parks. This template has in the last decade aggressively been applied by the Taiwanese government to other technological fields. The application of the "semiconductor development template" on other fields have however been considered disappointments, for instance in the case of biotechnology (see e.g. Swirbanks & Cyranoski, 2000; Hsu et al., 2005; Shih, 2009).

But could the perceived failure of these attempts rather be symptoms of unrealistic expectations on how industries and business networks actually emerge. In this case what is then the role of policy? To investigate these issues the emergence of a Taiwanese semiconductor business network will be studied from a resource interaction perspective (Håkansson & Waluszewski, 2002). The rationale of using a resource based perspective is that it can catch interdependencies beyond spatial and organizational borders even when they are not represented through direct relationships.

Literature review

In contemporary policymaking system approaches in general have provided a rationale for the public support of industrial development and business networks. In particular research on clusters and innovation systems have been highly influential to policymakers. In the innovation system perspective the innovative performance of a country depends to a large extent on how actors relate to each other as elements of a collective system of knowledge creation and use. Commonly understood is that the analytical focus is on the elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge (Lundvall, 1988; Edquist, 1997). Thus from the innovation system perspective it is the ecology of actors within a system, which through interaction create and diffuse innovations, that is of interest. The cluster framework proposed by Porter (1990) is a comparable concept. Cluster analysis has been applied and used extensively in policy circles (Teigland et al., 2004). Similar to innovation systems it does not have a universally accepted definition. A definition which is used by Porter (1998: p78) is:

> Clusters are geographic concentrations of interconnected companies and institutions in a particular field. Clusters encompass an array of linked industries and other entities important to competition.

Although the conceptualization of innovation systems and industrial clusters often differs from policymakers' use of these notions (Eklund, 2007; Lundvall, 2007) the policy implications are straightforward. That is, system approaches suggest the possibility of a certain level of control and implies that industries and business networks can be created, and the components necessary for their development identified. However empirical evidence of how industries or networks emerge often shows a messy and non-linear picture (Håkansson & Waluszewski, 2002; Shih, 2009). As suggested by Wedin & Waluszewski (2003: p4) the development of a technology or industry is a myriad of "expected outcomes as well as unexpected effects, where new and old solutions are tried and retried". With this understanding, the creation of networks is logically also an intricate issue which offers few certain pre-destined outcomes.

The reason, as described by Håkansson and Snehota (1989) is that companies interact with suppliers, customers, competitors, authorities and non-governmental organizations in order to create value. There are always anticipated and unanticipated effects from interaction, as neither the motives of people nor the content of the resource combinations and activity links they represent can be fully known in advance (Håkansson & Waluszewski, 2002; Ford et al., 2002). Thus interaction between various actors creates effects with both positive and negative consequences (Håkansson et al., 2009). The effects of prolonged interaction are that relationships between actors are established and interdependencies created between actors and resources. A result of the formation of relationships over time is that companies and organizations become increasingly dependent on each other, on their customers, suppliers and other counterparts. Thus actors, material and immaterial resources, and activities are systematically related to each other (Ford et.al., 2003). As relationships are systematically developed, Håkansson et al. (2009: p2) conclude that "they do not only connect dyads, but they do also connect indirect related companies in network-like structures".

From the IMP perspective the dictum holds that networks cannot be managed, however firms manage within networks (Ford et al., 2002; Öberg.

et al., 2007). How firms manage in networks has been described in the IMP literature (e.g. Håkansson & Waluszewski, 2002; Harrison & Waluszewski, 2008; Baraldi & Strömsten, 2009; Öberg & Brege, 2009). Few studies within the IMP tradition, however, have followed actual attempts of forced network creations and the involvement of policy. In this study we will follow the case of a business network in the semiconductor field, which has been argued to have been artificially created and managed by Taiwanese policy. The case will provide an opportunity to investigate an example of a forced network and the role of policy in creating and supporting a network. The paper is structured as follows in the section 2 the research design is presented. This is followed by the empirical case description in section 3 and an analysis in section 4. In section 5 the conclusions are discussed.

Research Design

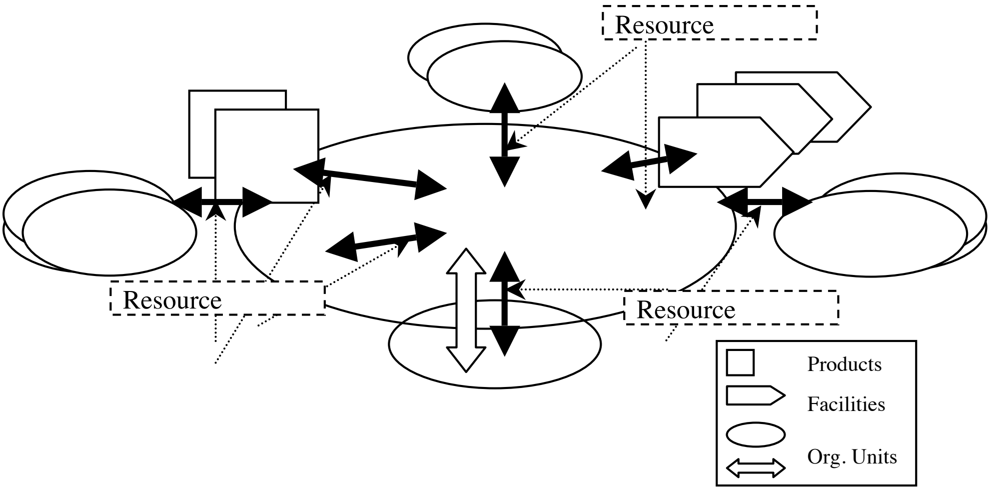
The Taiwanese semiconductor business network has often been portrayed as one of few examples of how policy has managed to create and control the emergence of an industry. In this context the example provides an opportunity to study forced network creations and to investigate the role of policy. The methodology used in this paper is a single case study (Yin, 1994). The material has been based on a number of secondary sources. Initially a number of interviews were made that gave me a structure of the semiconductor story. However as most of the events occurred in the 1970s and 1980s, the respondents had little first-hand information of what happened. Hence, this paper is principally based on a broad secondary literature survey synthesising different areas of literature such as economic geography and history, business studies, strategic management, organizational studies, and political science; and it draws on analysis of policy, industry and academic documents. The sources I have used include official policy documents, white papers, articles from academic journals, media coverage, industry reports, and statistical material. These sources have helped me to identify events, establish timelines, and have given me varied perspectives of the development processes. For example historical accounts have provided extensive development descriptions and analyses of the Taiwanese economy and, industrial and technological policies from the 1970s onwards. There are also a large number of publications, in academic journals, aimed at describing the Taiwanese economic miracle and the emergence of the semiconductor industry. The analyses made in the articles mostly discuss the role of the government and policy related research institutes in the development processes.

By using the above mentioned sources a case was constructed of how the Taiwanese semiconductor industry and a business network emerged. To structure the case and the analysis this study will apply the resource interaction model developed in Håkansson & Waluszewski (2002). It will be used to capture the processes in which heterogeneous resources[3] have been combined in the Taiwanese semiconductor industry and investigate the role of policy in the creation of the network. The resource interaction model investigates direct and indirect interaction between resources, on the basis that it is possible to catch interdependencies even when they are not represented through direct relationships (Håkansson & Waluszewski, 2002). The model has been applied to areas such as product, technological, logistics, and industrial development (see, e.g., Wedin, 2001; Håkansson & Waluszewski, 2002; Baraldi, 2003; Gressetvold, 2004; Jahre et al., 2006, Håkansson & Waluszewski, 2007, Waluszewski et al., 2009, Shih, 2009).

In the resource interaction model, resources are separated into four categories where two are mainly tangible or physical: (a) products and (b) facilities or equipment. The other two types of resources are mainly intangible or organizational: (c) organizational units and (d) organizational relationships. Below is an overview of the four types of resources (for a more detailed description see Håkansson & Waluszewski, 2002; 2007).

[3] An important assumption of resources is that they are heterogeneous. The notion of resource heterogeneity was early on suggested by Penrose (1959) who argued that a resource is "a bundle of possible services". In other words, it is not the resources per se but the services they create that make them valuable. In the IMP setting these ideas were adopted by Hägg and Johanson (1982) who proposed that the value of a resource depends on how it is combined with other resources. Hence resources alone are not productive and have no value unless they have a use or a function to fulfil in combination with other resources, i.e., forming a network-like structure.

Figure 1: An illustration of the resource interaction model and interfaces



Source: Modified from Waluszewski et al. (2009)

In the context of resource interaction, the identification of the resources that are relevant to study is a matter of choosing a focal resource through which ties to other resources can be identified. How the resources affect each other are investigated through the interfaces that are created between resources which are defined by Strömsten and Håkansson (2007: p29) as follows:

> No resource is used in isolation. Every resource has interfaces to both physical and organisational resources. […] "interface" is defined as "a place or area where different things meet and have an effect on each other".

As can be seen in Figure 1, both material (physical) and immaterial (organizational) resources are combined into a larger resource structure, connected through interfaces. The attention is directed to the interaction between resources, how they are combined and, developed over and beyond time, organizational and spatial boundaries. In the search for resource interfaces there are no ex-ante distinctions made concerning technological sectors, spatial or organizational borders. Instead the focus is on the search for related resource interfaces that occur across various technological, spatial and organizational fields (Strömsten & Håkansson, 2007). In this study the focal resource is an organizational unit, namely Taiwanese policy. By originating from the *focal resource* the interaction with other relevant resources creates a context (which is discussed in section 4). We can also investigate if the resource combinations occurred consciously or unconsciously. What follows hereafter is the empirical case describing the emergence of a Taiwanese semiconductor business network.

The emergence of the Taiwanese semiconductor business network

Taiwan has been considered one of the economic miracles of the twentieth century (World Bank, 1993; MOEA, 2005). The annual growth rate from 1952 to 1993 was 8.7 percent, an impressive number which few other countries have surpassed over such a long period of time (Chuang, 1999). In just a few decades, the Taiwanese economy went from being dependent on low-tech agricultural production to become a technological powerhouse and one of the leading semiconductor manufacturers in the world. How this was achieved has been studied extensively and often it is attributed to the government's active role in economic planning and coordination (Wade, 1990).

Today Taiwan is the twenty-fourth largest economy and has the fourth largest semiconductor industry in the world (TSIA, 2007; IMF, 2008). Based on the economic success of the industry, the government has lately been vigorously promoting a knowledge-based economy and aimed to transform Taiwan into a *green silicon island*. With the hopes of creating a second economic miracle, the semiconductor industry has played an important role as an inspiration and model to follow (MOEA, 2003). What now follows is an empirical account of how a Taiwanese semiconductor business network emerged. In the chronology below, some major events leading to the development of a Taiwanese semiconductor industry are outlined.

Table 1: Chronology: major events in the Taiwanese semiconductor industry

1961	The first foreign electronics companies, such as Philips and IBM, establish a presence in Taiwan.
1964	National Chiao Tung University establish the first semiconductor laboratory in Taiwan
1966	Texas Instruments establish the first semiconductor assembly operation in Taiwan.
1973	The Taiwanese government decides to develop a semiconductor industry.
	The first public research institute, Industrial Technology Research Institute (ITRI) is founded through the merger of three government laboratories in Hsinchu.
1974	The Electronics Research Service Organisation (ERSO), a sub-department of ITRI, aimed at developing semiconductor technology is founded.
1976	A technology transfer of a mature technology to ITRI from US semiconductor producer RCA Semiconductor and Materials.
1978	A special government expert committee created, known as the Science and Technology Advisory Group (STAG).
1980	Taiwan's first semiconductor company, United Microelectronics Company (UMC), a spinoff from ITRI, is founded.
	The Hsinchu Science Based Park is established.
	UMC is the first company to locate in the Hsinchu Science Based Park.
1986	The second spinoff from ITRI, Taiwan Semiconductor Manufacturing Company is founded.
	Semiconductor foundry as a business model is established with the emergence of TSMC.
1988	The Taiwanese semiconductor industry starts to grow rapidly.
2004	The Taiwanese semiconductor industry the fourth largest in the world.

The Taiwanese electronics industry – paving a way into semiconductors

The ambition of the Taiwanese government to make the transition into technology-intensive sectors formally appeared in the 1970s. The move was believed to be needs driven for reasons such as industrial development and international recognition (Chang et al., 1994). Prior to that, public policies had been aimed at measures which would build up a military capacity in Taiwan in order to launch an attack to retake mainland China. Initially, production on the island had been directed towards agriculture, but after the Kuomingtang[4] (KMT) assumed control over the former Japanese colony[5] in 1949 an import substitution policy was adopted. This stimulated the growth of new industrial sectors, such as plastics and textiles. In the 1960s, the Taiwanese leaders started to promote the export industry in order to increase national income and earn foreign currency as a result of reduced US financial aid.[6] The government policies encouraged the development of labour-intensive light industries (Wade, 1990; Chen, 1999).

By the 1970s the import substitution and export subsidy policies had turned the trade deficits into regular trade surpluses. The momentum was however temporarily brought to halt due to competitive pressure from emerging neighbouring economies and political crisis as a result of China taking over Taiwan's mandate at the United Nations in 1971. The global oil crisis in 1973 also brought an economic downturn. These events forced the Taiwanese government to search for new avenues through which sustainable economic and political development could be created. To realize these goals it was believed that the focus had to shift from the labour-intensive consumer goods industry to technology intensive manufacturing industry. The industries that were targeted for export promotion to attract foreign currency and investments had been identified with the help of Stanford Research Institute (SRI) in the early 1960s (Wade, 1990; Chen, 1999; Hsu & Cheng, 2002). As noted by Ernst (1997: p7): "SRI chose those product groups where American companies had strong interests: certain petrochemical intermediates, plastic resins, synthetic fibres, transistor radios, electronic components, watches and clocks". To motivate foreign investments, an export processing zone was also established in Kaohsiung in Southern Taiwan in 1965[7]. As a result, increased amounts of investment by US, Japanese and European electronics companies started to flow in. The operations, taking advantage of the low-cost labour, were concentrated towards the manufacturing of electronics and electronic components (Mathews & Cho, 2000).

As mentioned, an active export promotion policy was implemented in the 1960s. A reason for this was the reduced financial aid from the US, which

[4] The Kuomintang was the first political party of the Republic of China. During the Second World War, the KMT was the ruling party in China, but after the war internal conflicts and the growing strength of Communist party led to the defeat of the KMT, which had to flee into exile. The KMT leader Chiang Kai Shek brought over to Taiwan a whole administration and an army in 1948; a total of 2 million people moved.

[5] Taiwan was a Japanese colony between 1895 and 1945

[6] In the 1950s it was financial aid from the United States that helped Chiang Kai Shek to maintain a large military force without overheating the weak economy.

[7] The first in the world; various tax incentives were given to local as well as foreign companies interested in investing in the zone.

prompted the Taiwanese government to seek income and foreign currency through other means. Generous incentives were given to foreign companies willing to invest in Taiwan. The foreign direct investments came in the field of consumer electronics and the pioneers were IBM and Philips. IBM had set up operations in Taiwan in the late 1950s, and also established an affiliate producing core wires by the early 1960s. The business model was geared towards moving labour-intensive stages of final assembly to low cost countries. Similarly, Philips took advantage of low cost manufacturing by establishing a subsidiary in Taiwan in 1961, manufacturing TV sets, audio equipment and related components. Soon an inflow of Japanese direct investments came, the first was Matsushita that set up a majority owned joint venture in 1962. Up to the mid-1980s this venture was one of Matsushita's major production facilities in South East Asia. Sanyo followed in 1963, Hitachi in 1965, and Sony in 1967. By the 1970s, most of the leading Japanese electronic producers had established a presence in Taiwan or were engaged in labour intensive assembly with a growing share of output going to Japan or Japanese affiliates in Asia. American companies had also realized the benefits of being in Taiwan. For instance, in 1964 General Instruments directed production of transistor radios to Taiwan (Ernst, 1997; Mathews & Cho, 2000).

While several companies had set up subsidiaries, others acquired a direct stake in existing local companies. The latter strategy was for example used by Toshiba, which had in the 1950s acquired a 5 percent equity-share in Tatung Co. Taiwan's only integrated electronics company at the time. Initially, Tatung was only a distributor, selling various electronic products produced by Toshiba. In the 1960s the cooperation deepened and Tatung also received technology licenses from its Japanese partner, allowing the company to become a supplier of key components, such as high-end compressors, picture tubes and LCDs. Other Japanese companies such as Fujitsu followed with a similar approach when it in 1973 established a joint venture with Tatung. The deal gave Tatung the rights to both sell and service Fujitsu computer systems and peripherals. These events eventually led to a number of joint ventures and OEM (Original Equipment Manufacturing) contracts with Taiwanese companies. Thus the investments made by foreign manufacturers of consumer electronics gave rise to a rapid growth in demand for electronic components produced in Taiwan. Although most of the high value-added key components were imported, both local production and capacity were increased (Ernst, 1997; Tu, 2001).

The foreign direct investments played an important catalytic role for the emergence of a Taiwanese electronics industry. For example, the Japanese companies offered intensive on-the-job training as well as developing close links with local suppliers that focused especially on the domestic market. A significant scale of local linkages was created by the foreign investments. Furthermore, the companies that invested provided the local employees and suppliers with education, knowledge and technology, although not advanced. Some of the employees also started new local companies. For instance General Instruments' Taiwanese affiliate itself gave rise, through former employees, to the founding of 11 local companies. In addition to being an incubator for local suppliers, foreign companies also established other facilities. Matsushita for instance created the Matsushita Electric Institute of Technology in 1981 with a work force of around 40 researchers (Ernst, 1997; Lin, 2003).

The events mentioned above preceded the growth of a domestic semiconductor industry. The first company to introduce semiconductor related business to Taiwan was General Instruments, who established a semiconductor assembly plant in Taiwan in 1967. Between 1969 and 1973, other multinational companies such as Philips, RCA and Texas Instruments followed suit and established their semiconductor assembly operations in Taiwan (Mathews & Cho, 2000). By contrast, the first semiconductor related research activities in Taiwan had local roots as discussed by Chang & Tsai (2000: p186): "The theory and technology of semiconductors was first systematically introduced in Taiwan when National Chiao Tung University started a course in 1960. The university built a semiconductor laboratory in 1964 that succeeded in manufacturing its first integrated circuit in 1965. National Chiao Tung University then chose semiconductor technology as the main focus of its curriculum, with the aim of training more high-tech manpower". According to Chang & Tsai (2000), National Chiao Tung University later also cooperated with governmental units and provided a foundation for the semiconductor industry in terms of basic research and human resource development.

A government initiative to create a new industry

Foreign direct investment was a factor that contributed to the emergence of a Taiwanese electronics manufacturing industry. Although the manufacturing of electronics products brought income to the export sector, those activities were believed by Taiwanese policymakers to be isolated from the rest of the economy and to have little value in terms of industrial development. The reason expressed by Lin (2003) was that the foreign companies saw Taiwan only as a low cost manufacturing resource. Furthermore, there were no local companies conducting any technologically advanced R&D. However, the fast growth and the volume of applications possible, in for example consumer electronics, telecommunications and industrial electronics, made the electronics industry an attractive sector for Taiwanese policymakers to promote. With this ambition, the main issue became to find a key technology that would help the Taiwanese electronics industry to develop in the direction of technology-intensive products. Hence, expert advisors suggested that Taiwan should develop semiconductors, specifically integrated circuit design and manufacturing technology in order to stimulate innovation throughout the island's electronics industry. Chang et al. (1994: p163) provide the following explanation for why the Taiwanese government decided to concentrate on semiconductors:

> Since the integrated circuit was introduced in 1958, its small size, low power consumption, rapid operating speed, reliability, and low cost per electronic function have led to significant changes in all electronics products, including consumer electronics. If the IC industry were developed in Taiwan, a spillover effect would be generated for industries which use ICs. The IC was thus selected as the key technology to be developed.

Taiwanese companies had however no experience in making semiconductors. Beside the foreign manufactures there were no local companies with experience or knowledge concerning semiconductor design or manufacturing. A task force, The Technology Advisory Committee (TAC), funded by the Ministry of Economic Affairs (MOEA) was therefore set up with the mission of investigating how to carry out a development strategy for the semiconductor industry. The TAC was formed by Y.S. Sun[8] (at the time the Minister of Economic Affairs) and P.W. Yuan, an engineer at RCA, in Princeton. The formation of TAC had been preceded by the belief that the key to a successful technological upgrading was to leverage the experience and knowledge of overseas Chinese engineers working in the US (Mathews, 1997). It was this group of highly skilled Chinese engineers, and academic scholars, working at various semiconductor companies and universities in the US that became the recruiting base for the TAC. Eventually the TAC also provided the guidelines concerning how to develop a semiconductor industry (Tung,

[8] Sun was responsible for laying the foundations for Taiwan's technological upgrading. Both he and Yuan agreed that the electronics industry would be the key to Taiwan's transformation, and that semiconductors should be a key technology. Furthermore, they believed that the required knowledge needed to be leveraged from abroad.

2000). The main areas of the strategy are highlighted below (Chang et al., 1994: p163):

1. TAC became responsible for the planning of the development. This was decided because there was no local experience in integrated circuit design and manufacturing available.
2. Since the gap between advanced semiconductor producing countries and Taiwan was very large, the main strategy to quickly develop an industrial base was through technology transfer.
3. The purpose of introducing semiconductor technology was to create an industrial base and to establish this kind of technology in Taiwan. The technology would have to be assimilated and developed. For this purpose a new research institute, ITRI was formed to reach the initial goals.
4. Over a period of 4 years, 410 million NTD (13 million USD) was to be invested by the government to purchase the manufacturing technology, product design and training personnel

The creation of a public research institute and technology acquisition

Who would take the lead in developing a new industry? The private sector companies, the majority of them being small or medium sized[9], were not technologically sophisticated enough. Neither did those companies place much emphasis on increasing R&D activities and investments (Liu, 2002). The few large companies, all involved in traditional industries, were reluctant to invest in new unproven industries (Mathews & Cho, 2000). Consequently it was believed by policymakers and experts that "no existing industry in Taiwan could lead the way in developing future high-tech industries for more than ten years" (Chang & Hsu, 1998: p350). In addition, the Taiwanese capital market was underdeveloped and financial institutions were conservative in lending out capital for risky ventures (Saxenian, 2000). Due to these circumstances, there was no other choice than for the government to assume the responsibility of being in the frontline in building up a semiconductor industry. In order to commence semiconductor related activities, the Ministry of Economic Affairs merged three government

[9] According to Saxenian (2000), SMEs make up 95 percent of all companies in Taiwan. MOEA states that 90 percent of all Taiwanese companies in the 1950s were enterprises with 10 or fewer employees. In the 1960s the proportion of SMEs was 95 percent.

laboratories located in Hsinchu to form ITRI in 1973.[10] The government commissioned the newly founded research institute to carry out the introduction and assimilation of semiconductor technology. ITRI was thus the sole institution in Taiwan chartered to develop a semiconductor industry. With that purpose, ITRI established in 1974 the Electronic Research and Service Organization (ERSO)[11], a unit specifically concentrating on semiconductor technology. The responsibility for planning and coordination was however still in the hands of the TAC. Since no domestic proprietary technology existed. TAC decided to acquire it from abroad (An, 2001). What technology would be suitable to license?

The first integrated circuits had already been developed in 1959[12], and by the 1970s a large number of integrated circuits with various features and technology platforms existed. In the mid 1970s the most advanced integrated circuit designs had a 3.0 micron bandwidth. After some initial enquiries however, no companies were interested in transferring cutting-edge technology to ERSO. The only technologies available for licensing were 7.0 micron chips. After lengthy discussions concerning the opportunities, the conclusion reached by the TAC was to obtain low power, high density technology that would provide submicron development potential. The main points in the discussions of the TAC were according to Chang et al., (1994: p164) as follows:

1. It would be very difficult to license an advanced technology. Either the companies that possessed that technology would not agree to a transfer or the price would be very high. It was believed by the TAC that it would be more feasible to license a mature technology with lower competitive advantage.
2. The 7.0 micron technology was mature, and thus also held several advantages for a country which had no prior experience in semiconductor manufacturing and development, including higher consistency, complete technical documents, many skilled technicians, and effectiveness in the operation of the equipment.
3. Products manufactured with 7.0 micron technology were already out on the market and feedback was available concerning process technologies, product development, design technology and marketing channels. Acquiring the 7.0 micron

[10] Union Industrial Research Laboratories, Mining Research and Service Organization, and Metal Industrial Research Institute were donated to ITRI by the Ministry of Economic Affairs
[11] At the time the lab was known as Electronics Industrial Research Center, in 1979 the name ERSO was adopted.
[12] By Kirby, at Fairchild Semiconductor

technology would therefore allow Taiwan to learn about all aspects of integrated circuit technology from R&D to commercialization.

The search for partners was conducted by ITRI which believed that American semiconductor companies were the ones most suitable to license technology from. Hence, over twenty requests to companies in the US were sent out and a handful of companies returned a proposal for a technology transfer. After the Taiwanese selection committee had visited the prospective companies, two were selected as potential partners, RCA Semiconductor and Materials (hereafter RCA) and company X. The cost for RCA's deal was twice as high as the one given by company X, but the terms of the company's proposal were better. RCA's proposal included technology, process design and manufacturing management skills for integrated circuit fabrication, whereas company X's proposal consisted of process design and design technology. However, another dimension that came into play was also that RCA could provide a year-long training for 35-40 ITRI engineers at its laboratories in the US. In contrast company X only suggested training for 3 months for 3-4 persons. Since it was believed by TAC that the success of the project would be reliant on the extensive training of human resources, the difference in the suggested training of Taiwanese engineers came to be the critical factor in the decision-making. RCA's proposal was considered as the better choice. Although the guiding principle had been to select the deal with the lowest price, the technology content and personnel training proposed by company X was believed not good enough to achieve the goal of introducing semiconductor technology in Taiwan. The technology that was licensed to Taiwan was the so called Complementary Metal Oxide Semiconductors (CMOS), which originally was developed by RCA[13]. The technology corresponded to the goals of TAC to acquire a "low power, high density technology that would provide submicron development potential". Targeting this technology meant also that ITRI would not be competing directly with established manufacturers (Chang et al., 1994; Chen & Sewell, 1996; Hung et al., 2005).

Responsible for coordinating the technology transfer was ERSO. While the agreement with RCA was being negotiated talented young Taiwanese engineers were recruited and trained at ERSO for a period of time while

[13] CMOS technology was developed at Fairchild Semiconductor in 1963. In 1968 the first CMOS based ICs were developed at RCA. At the time it was a low power but slow alternative to the standard NMOS (another technology which ITRI wanted to license but proved to be too expensive) and TTL technologies.

waiting for the pending transfer. After the agreement with RCA had been finalized in 1976, 37 engineers were sent to different laboratories and plants in the US operated by the company for one year of technical training. Many of these engineers would later become the corporate leaders of Taiwanese semiconductor companies (Chang & Hsu, 1998). The agreement with RCA included the transfer of a 7.0 micron CMOS process technology, product specifications, design and testing technology for a digital electronic watch. Assistance in building a semiconductor plant and training of personnel were also included in the licensing agreement. While the engineers were sent to the US for training, ERSO were setting up a 4 inch wafer pilot plant for semiconductor manufacturing back in Hsinchu, Taiwan. When the engineers returned in 1977 the plant was already operational for test runs. The same year the first integrated circuits were produced by the pilot plant. The standard of the product complied with what had been agreed in the licensing contract (Chang et al., 1994).

ITRI had accomplished the introduction of semiconductor technology to Taiwan. Of course Taiwan was still far from catching up with advanced nations but the main goal was to learn more about semiconductor technology, and to accumulate knowledge. For this goal, a pilot plant, with design, manufacturing and testing capabilities had been built, and was geared towards producing simple semiconductors. As noted, RCA had developed the first CMOS integrated circuits, but CMOS was at the time not a widespread technology. RCA was actually about to withdraw from the semiconductor industry and the licensing deal with ITRI was an opportunity to squeeze some last income from a mature technology. The 7.0 micron CMOS was mature, and far behind the worlds leading LSI 2.0 micron circuit designs, nonetheless for ERSO this was a way of gaining access to the world of semiconductors. In retrospect, the licensing of CMOS technology proved to be a wise choice. First of all ITRI did not have to directly compete with established producers on a global market. Second the market share of CMOS was relatively small at the end of the 1970s, but started to expand rapidly afterwards to become the most used technology in IC design today.[14] After RCA withdrew from the semiconductor industry in the early 1980s, ITRI also inherited the intellectual property portfolio from RCA that had been related to CMOS technology (Mathews and Cho, 2000).

[14] Originally a low-power but slow alternative to TTL, CMOS found early adopters in the watch industry and in other fields where battery life was more important than speed. Some twenty-five years later, CMOS has become the predominant technology in digital integrated circuits. This is essentially because area occupation, operating speed, energy efficiency and manufacturing costs have benefited and continue to benefit from the geometric downsizing that comes with every new generation of semiconductor manufacturing processes.

ERSO's semiconductor fabrication plant had been built under the guidance of RCA. After being able to produce integrated circuits in 1977, used in electronic watches, ERSO soon also started to produce experimental semiconductors by using its own designs. By 1979 ERSO were getting better yields from these integrated circuits than what the licensed technology had given. In the early 1980s ERSO could provide CMOS of 4.5 micron and in the mid 1980s of 1.0 micron (Chang et al, 1994). In 1979 ERSO also established a customer relationship with a Honk Kong electronic watch producer that bought integrated circuits from the pilot plant. The order of 10000 integrated circuits was small and the owner of the Hong Kong firm was a former college classmate of the person responsible for running the pilot plant, Shih Ching Tay. This deal provided ERSO with an opportunity to interact with a user. (Tu et al., 2006) The total amount of capital invested from 1975 to 1979 was 410 million NTD dollars (roughly 12 million USD)[15]. After the introduction of CMOS technology the government's commitment also increased. Between 1979 and 1983, 670 million NTD was to be invested. The goal that had been set up by ITRI was to upgrade the technology from 7.0 to 3.0 micron (Chang et al., 1994).

In 1979 the Taiwanese semiconductor sector still only consisted of ERSO's plant and a handful of foreign assembly plants. Local companies were not interested in semiconductors, as it was considered a risky and unproven business. The technology which ERSO had acquired and continued to develop was still far behind the global standards, which were getting to below 2.0 micron bandwidth. In addition, there was no real infrastructure to support high-tech development in Taiwan and the investments required to resolve this issue would have to be quite large (Chang & Tsai, 2000).

Hsinchu Science Park and the first ITRI spinoff - UMC

The ambition of creating high-tech industries in Taiwan had strong support in policy circles. A person who came to play an important role for the high-tech development was former Minister of Economic Affairs, Li Kwoh Ting. He had taken an initiative for the creation of a permanent advisory body to the government in science and technology issues. The group that was established in 1978, headed by Li, was named the Science and Technology

[15] It was a substantial sum to be invested by the Taiwanese government in a single technology, but compared to the research budgets of large semiconductor companies it was not a considerably large R&D budget.

Advisory Group[16] (STAG) consisted mainly of overseas Chinese with technical backgrounds. Many of the advisers in STAG had worked in the US and experienced the growth of high-tech regions such as Route 128 and Silicon Valley. Based upon their experiences, STAG suggested that Taiwan needed a specialist infrastructure to support advanced industries such as semiconductors (Saxenian & Hsu, 2001; Yu, 2007). The ambition to set up a specialized infrastructure gained adherence in the Executive Yuan, and under the sponsorship of the National Science Council (NSC) a science park was to be established. The decision was however not well received in all political camps. The efforts to set up a science park were met with considerable opposition and scepticism in the Taiwanese Cabinet. The NSC was nevertheless successful in securing land near Hsinchu, where both the ITRI campus and National Chiao Tung University were located. In 1978 210 hectares of land had been expropriated by the Hsinchu county government to create the new park and in 1980 the Hsinchu Science Park Administration was established (Mathews & Cho, 2000).

The establishment of Hsinchu Science Park was to facilitate the creation of a high-tech industry, but there where no local companies that could locate in the park. What existed were a few foreign subsidiaries that were involved in the downstream stage of packaging and testing semiconductor products. There was also ERSO which had set up a pilot plant manufacturing semiconductors, but other than that there were no local companies specifically involved in semiconductor development and production. Since no private Taiwanese companies were involved in Large Scale Integration (LSI) and semiconductor related R&D activities, the ERSO management decided to create a company (Chang & Hsu 1998; Mathews 2000). It was believed by ERSO that the prospects of a Taiwanese semiconductor industry would be threatened if foreign companies would first establish subsidiaries (Liu et al., 2005). Hence, the pilot plant at ERSO was to be spun off, and form the foundation of a new company named United Microelectronics Company (hereafter UMC). The spin-off would mark an important milestone in the development of a semiconductor industry. ERSO was now ready to exploit commercial opportunities with the technology that had been acquired 3 years earlier (Chen & Sewell, 1996). The idea of a spin-off from ITRI was however novel, and there were difficulties with raising capital for a project of this kind. ITRI sought funding from both private and public sources, and in the end the majority of the capital was provided by the government (mainly by securing

[16] STAG remains the main science and technology advisory group to the government up to the present. Since 1979, together with the NSC it has also served as the main organ for science and technology policy.

funds from state owned banks). A large stake was also taken by five large private companies (Saxenian, 2002).

ERSO not only spun off the pilot plant, there was also an extensive technical personnel transfer in which around 180 persons were transferred to the new company. In addition, the process technologies which had been modified and developed at ERSO were given to UMC, mainly a 5.0 micron CMOS process technology. Furthermore UMC received ten Application Specification Integrated Circuit (ASIC) products as well, including integrated circuits for calculators, melodies, timers and telephones. By 1982 the transfer process had been completed and the operations of the new company began the same year (Chang et al., 1994). UMC pursued a niche strategy by focusing on ASIC products that had been transferred from ERSO. The first customers had been inherited from ERSO, but the company also started to attract low end electronics manufacturers from Taiwan and Southeast Asia as customers. The strategy to concentrate on these customers meant that UMC was able to avoid direct confrontation with the large Japanese semiconductor companies which were concentrating on standard products such as memory. Focusing on a niche market turned out to work well, and in November 1982 UMC had reached break-even point (Liu et al., 2005).

Even with the ongoing spin-off of UMC and the ensuing reorganization, ERSO remained active with continued development of the licensed technology. By 1980 ERSO engineers had reduced the bandwidth of the process technology from 7.0 micron to 5.0 micron. This was further improved to 4.5 micron the year after. Although this could be seen as an achievement in itself for a new organization with little experience in semiconductor R&D, ERSO was not getting closer to catching up with the leading standards. At the time the world's top semiconductor manufacturers were producing products using Very Large Scale Integration (VLSI) technology of 2.0 micron bandwidth. It was clear that Taiwan was still far behind the top countries such as the US and Japan in terms of technological levels (Mathews & Cho, 2000).

Thus, with the current rate of progress would it be possible for Taiwan to catch up with the advanced nations? The advisers at STAG believed that although ERSO was successful in introducing and assimilating the CMOS technology, Taiwan was still far behind the advanced semiconductor nations, and some argued that the gap was actually increasing. The STAG advisers strongly advised that Taiwan should set its target at achieving VLSI capacity of 1.0 micron standard or higher. This would bring the technology competence in Taiwan on par with the top companies in the world. ERSO strongly objected to STAG's advice and argued that Taiwan should be patient in its efforts to develop an industry, and not take on that much risk by directly try to challenge the large semiconductor companies. This could quickly jeopardize what had already been built up. Officials at the state departments such as the *Ministry of Finance* and the *Economic Council for Planning and Development* were also opposing the suggestion from STAG. These departments were more concerned with issues related to macro-economic stability and were not interested in promoting a single technology. STAG's suggestion to achieve VLSI capability was however supported by some high government officials, such as the president and the premier. Hence, in 1983 it was decided that the government would invest 2.9 billion NTD (roughly 85 million USD) to pursue the plan to achieve 1.0 micron VLSI capability by 1988 (Chang & Tsai, 2000; Mathews & Cho, 2000).

This was a very ambitious goal considering the then current state of the Taiwanese semiconductor sector and the small involvement of the private sector. As earlier, the government entrusted the VLSI project to ERSO. UMC had also tried to convince the government that it was capable of handling the task, but it was considered too risky to hand over such a mission to a newly started company. Thus the plan was that a VLSI plant would be set up at ERSO. But where would the VLSI technology come from? Instead of turning to another large company as before, ERSO signed an agreement with two Silicon Valley start-ups, Mosel and Vitelic, to develop VLSI semiconductor chips. Already by 1985 a bandwidth of 1.25 micron had been achieved at ERSO for the CMOS technology, and in 1986 CMOS memory chips of 1.0 micron were available. Taiwan now had the capability of designing 1.0 micron chips. There were however no fabrication facilities in the country to produce these semiconductor chips (Mathews, 1997; Mathews & Cho, 2000).

The growth of design capabilities and the emergence of TSMC

The results of the VLSI project were advanced design capabilities and "state of the art" technology in one of ERSO's special laboratories. Where was Taiwan heading from here, should the designs be licensed to third parties for fabrication? The problem with lack of fabrication capacity became more obvious with the growing number of semiconductor design companies in Taiwan. As mentioned earlier ITRI had started to transfer the capabilities and resources which had been built up, the first one being UMC. In 1982 ERSO had also spun off the first two independent Taiwanese semiconductor design houses, first *Syntek* and shortly thereafter *Holtek*. But if no private sector companies would willingly get involved in the semiconductor industry, ITRI would have to create an industry through spin-off companies (Mathews & Cho, 2000).

In addition to the VLSI laboratory, ERSO had in 1985 set up a Common Design Center for chip design companies to develop application products, which was mainly aimed at start-up companies (Liu et al., 2005). This encouraged several overseas Taiwanese from Silicon Valley to return to Taiwan and start their own companies or expand their business with the support of the Common Design Center (Chiang & Hsu, 1998; Mathews & Cho, 2000; Liu et al., 2005). The semiconductor design industry in Taiwan did not really take off, however, even though the technological levels had been raised and were approaching those of the advanced companies. A reason was not only that there were no customers, but also a lack of fabrication capabilities in Taiwan contributed to the situation (Chen & Sewell, 1996). UMC was the only semiconductor company in Taiwan with a fabrication plant prior to 1987 (An, 2001). ERSO also had some fabrication capacity since it had retained a part of the plant for continued research after the UMC spin-off. Nevertheless, none of these plants were intended for VLSI manufacturing, and as noted earlier the development was moving towards VLSI technology. This capability was believed to be necessary in order to catch up with the advanced semiconductor nations. So how would the products developed with VLSI technology be manufactured?

In 1985 Morris Chang had become the new president of ITRI. Chang, an overseas Chinese with a Ph.D. from Stanford University in engineering, had three decades of working experience in the semiconductor industry and prior to joining ITRI was head of the global operations department at Texas Instruments. In Chang's first week at ITRI he proposed a new spin-off from ERSO. He suggested that this spin-off should be focusing strictly on manufacturing chips, i.e. *semiconductor foundry*, for local and international customers based on VLSI technology. The rationale for this was mainly based on two reasons. First, most of the top 20 semiconductor companies in the world did not have financial capital to quickly upgrade their fabrication facilities to VLSI-standard. Second, the growing Taiwanese semiconductor design sector needed fabrication plants to meet their production needs (Liu et al., 2005).

The idea was quite novel, since up to now the semiconductor companies had been vertically integrated, involved in both design and manufacturing. Although these two activities are separable, the companies with fabrication capabilities were also designing their own semiconductors in order to reduce the risk of having semiconductor designs copied. The new spin-off from ITRI would be the first company focusing strictly of foundry. The proposal to create a pure foundry company was accepted by the government, but it was not to be fully funded by the state; instead it was to have both public and industry support. This would be a way to push the private sector to participate in the semiconductor industry. The government gave ITRI the task to find a multinational company as a sponsor. The ambitions for the new company was to become a global semiconductor company, and in order to receive credibility, technology and a cross licensing portfolio it was believed that a venture with a leading semiconductor company would be best (Chang & Hsu, 1998; Mathews & Cho, 2000).

The possibility of creating a large scale VLSI semiconductor business through financial support from the government and combined with engagement from an international semiconductor user, appeared an attractive solution. Interest was shown from four multinational companies: Texas Instruments, Intel, Philips, and Matsushita (Mathews & Cho, 2000). All of these companies, with the exception of Intel, already had prior production activities in Taiwan. Philips was the pioneer, starting production in Taiwan when the company established its production of TV sets, audio equipment and related components in 1961. In 1962 Matsushita established a production facility in Taiwan, to be followed by among others RCA and Texas Instruments. After the Taiwanese government had negotiated with all four companies, Philips proved to be the only serious candidate. In 1986 it was announced that the Taiwanese government and Philips would be the largest shareholders of the new company, Taiwan Semiconductor Manufacturing Company (TSMC)[17], and the company was established the year after (Chen & Sewell, 1996). ITRI provided the technical personnel, around 150 persons, of which most had been involved in the VLSI project. ERSO also spun off its 6 inch VLSI manufacturing plant that became TSMC's first fabrication facility. With this TSMC became the first dedicated foundry in the world, and pioneered a concept which became a central element of the semiconductor supply chain. Since Philips production activities in Taiwan already included semiconductor assembly operations, the step to an engagement in semiconductor foundry was already locally established (Saghafi & Davidson, 1989).

Through Philips' engagement, TSMC not only received a financier but also a large, skilled and demanding customer. In the technology area, Philips agreed to transfer 2.0 and 1.5 micron process technology to produce VLSI

[17] According to Saghafi & Davidson (1989) 10 billion NTD was raised. Philips became the largest private shareholder with 27.5 percent of the equity. The largest shareholder was the Taiwanese government, with 48.3 percent of the equity.

devices. For more advanced technologies Philips, would be paid royalty fees. The condition for the deal was that the new company would not become a competitor to Philips own products in Taiwan. The initial technology inputs supplied by Philips accounted for 80 percent of TSMC's original capability. Philips transferred its portfolio of cross licenses to TSMC to avoid the company being accused of infringing intellectual property rights of other semiconductor companies, something which had happened to several upcoming Korean semiconductor companies. In addition, Philips also supported TSMC with product and process know-how, but more importantly what was gained was legitimacy for the new company. As a result of the extensive support, TSMC experienced strong growth and was successful in upgrading its technology to world standards in a short period of time. Until the end of the 1980s TSMC had to rely on the support from Philips in order to be able to produce advanced integrated circuits. However, at the end of the 1980s both the customer base and the knowledge of making advanced semiconductors had grown so much that TSMC was able to design 0.8 micron semiconductors without any technical support from Philips. In the early 1990s, a decade after the operation started, TSMC's annual sales surpassed 1 billion USD, and the production activities included design and manufacturing of semiconductor chips (Mathews & Cho, 2000).

A growing semiconductor industry

As discussed earlier, by the time the government decided to promote semiconductors many foreign electronics companies had a steady presence in Taiwan. Philips had already been involved in Taiwan since the early 1960s when the company had set up a transistor and television tube factory, which today is the largest of its kind in the world and the main supplier of tubes to the Philips group. The company's commitment came to grow stronger over the years. Hence, when the Taiwanese government searched for a partner to form TSMC, Philips was a potential sponsor. The reasons that Philips turned out to be the only serious candidate was not only because the company had the financial and technical resources but equally important was its long term dedication to Taiwan. It must be taken into consideration that TSMC was an unproven business idea and the burden of proof was on ITRI. The other companies, Texas Instruments and Intel were just not convinced of TSMC's potential, but for Philips the incentive to invest was the opportunity to gain a stronger foothold in the emerging Taiwanese market (Chang & Tsai, 2000; Mathews & Cho, 2000).

The development of TSMC functioned as a catalyst for the continued start-up of new semiconductor companies[18] in the Hsinchu region. Around TSMC and its interaction with customers such as Intel and Texas Instruments, a structure of related companies started to emerge. ITRI had also continued to run its R&D operations, and fuelled by its proven spin-off strategy, projects became companies as soon as technologies were considered ready for commercialization. The research institute maintained a liberal view on employees' ambitions to create new companies, direct as well as indirectly[19], and this benefited the enlargement of the semiconductor industry. With the growing opportunities, Taiwanese private capital was starting to flow into the semiconductor industry in larger amounts (Chang & Hsu, 1998).

UMC, the only other company in Taiwan at the end of the 1980s with fabrication capabilities, had already been listed on the Taiwan Stock Exchange in 1985. But although the company was profitable it was lagging behind TSMC in technological sophistication. For example, in 1987 when TSMC's technological capabilities were almost similar to the world leading producers, i.e. close to 1.0 micron, UMC only had 3.5 micron process technology. Furthermore, while TSMC was attracting large multinational companies as customers, UMC was serving mostly "small" customers (Chang & Hsu, 1998). However this did not mean that UMC was unsuccessful, the CMOS technology which the company inherited from ITRI was also becoming a standard technology used in producing integrated circuits. Initially ITRI had chosen to license a mature CMOS technology from RCA because the more advanced technological solution could not be afforded. Although CMOS based integrated circuits were a somewhat slower alternative to some more advanced solutions, it was also less power consuming. This meant that CMOS became an attractive solution for products where low power consumption was of greater importance than speed, for example in the watch industry. Since the CMOS technology was considered by the dominating US and Japanese semiconductor companies as obsolescent, it became a niche product which UMC later became one of the few to supply. About two decades after ERSO started the development and production of CMOS technology it had emerged to become one of the predominant standards in integrated circuits[20] (Mathews & Cho, 2000). TSMC and UMC had proven to be triumphant cases which

[18] E.g. Destiny Technology Corp., Realtek, Weltrend, Sunplus, ICSI, Eltron et cetera.

[19] This high mobility of labour was also a major contribution to the successful development, according to Saxenian (2001).

[20] It was a combination of CMOS features, for example the geometric downsizing, the development of operating speed together with energy efficiency, and the low manufacturing costs that made CMOS a dominant standard in semiconductors.

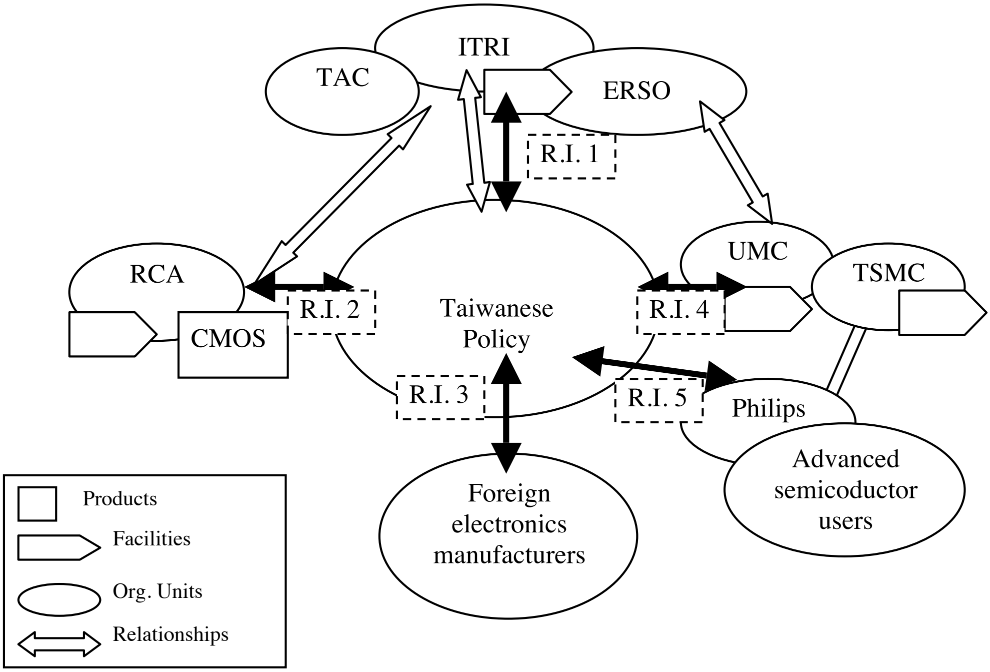
encouraged private sector and non-public investors to participate in an industry which had earlier been dominated by government organizations. The development progressed quickly, and by the early 1990s Taiwanese companies had similar technology levels to those of the advanced global semiconductor manufacturers (Chang & Hsu, 1998; Hsu & Cheng, 2002).

Today the semiconductor industry is considered an icon of success in Taiwan. At the end of 2005, Taiwan Semiconductor Industry Association (TSIA) estimated that 60 percent of worldwide semiconductor foundry, package and testing revenues were generated by Taiwanese semiconductor companies, with a majority of them located in Hsinchu. For worldwide revenue in semiconductor design as well as dynamic random access memory, Taiwanese companies held around 25 percent. The total economic value generated by Taiwan's semiconductor industry totalled 1118 billion NTD (roughly 33 billion USD) at the end of 2005 (TSIA, 2006).

Key interfaces in the semiconductor business network

The story of the emergence of the Taiwanese semiconductor business network is both an interesting and impressive example of industrial development. Some of the major actors that contributed to the development were policy actors, foreign manufacturers, public research institutes and local industry. Figure 2 below is a network map of some of the key resources in the emergence of the semiconductor business network. The following analysis will take a closer look at Taiwanese policy's interfaces to: 1) ITRI & TAC; 2) RCA and the CMOS technology; 3) Foreign electronics producers; 4) Spin-off companies and; 5) Advanced semiconductor users. These interfaces will illustrate the role of policy in the emergence of the Taiwanese semiconductor business network.

Figure 2: Network map of key resources involved in the semiconductor case



1. Interface with ITRI & TAC

In 1973 the public research institute ITRI was established and commissioned by the Taiwanese government to develop semiconductor technology. Accordingly this was the formal start of a policy created Taiwanese semiconductor business network. The capabilities and knowledge within ITRI emerged over an extended period of time. For example national Chiao Tung University had already established Taiwan's first semiconductor laboratory in the early 1960s and played a significant role in training and educating personnel at ITRI. Another important factor in the establishment of the local research institutes was existing sources of semiconductor knowledge outside of Taiwan. Much of the knowledge of semiconductors stemmed from Taiwanese professionals working within existing companies and research environments. Almost all the experts engaged in the expert committees that the Taiwanese government created, were US-based Chinese and Taiwanese engineers involved in semiconductor research or business.

Members of the *Technology Advisory Committee* (TAC) were especially influential in establishing a local structure. It was these experienced semiconductor experts who helped set up ITRI, and ERSO in 1974. Hence, already from the start of attempting to develop a domestic base of semiconductor technology, Taiwanese policymakers and engineers were interacting with individuals working in world leading semiconductor companies and research units. This created a large number of organizational interfaces not only to other developing structures but also to existing producing and using structures mainly in the US. It was through these interfaces which ITRI were able to access technologies and knowledge.

2. Interface with CMOS technology and RCA

A local structure was built up through using experienced semiconductor professionals and organizational units outside of ITRI. In addition to the creation of such organizational interfaces, through policy support, there were also important physical interfaces that shaped ITRI and the Taiwanese semiconductor business network. One important physical interface was the mature CMOS technology that ITRI licensed from RCA in 1976. Although the government provided the funding to develop semiconductor technology it was not going to be developed instantaneously. ITRI needed first an existing technology to experiment on and learn from. However no advanced producers were interested in licensing any cutting edge technology to Taiwan. The only viable option was to license mature and less advanced technologies. The decision to license an "obsolete" technology from US producer RCA served as a way to educate ITRI and its personnel on how to manufacture semiconductors. The fact that it was mature had several advantages; one was that the cost of the technology was within the proposed budget. Another advantage was that it was already thoroughly tested in existing producing and using structures. In other words the technology already had established user and producer interfaces. Although the technology lacked novelty, which was considered as a weakness by the multinational companies, it made it possible for ITRI to work on solutions suitable for both production and use already in the 1970s. Consequently it was not only the new institutions that policymakers created that had an imprint on the emergence of a business network. ITRI's ability to take advantage of already embedded resources, such as a mature technology was decisive.

About two decades after ITRI started to engage in the CMOS technology it had emerged to become a dominant standard in integrated circuits. From a using perspective the features of the mature technology (for example, low power consumption) were much more important than novelty and untried solutions. The CMOS technology later became a niche product which ITRI's spin-off UMC was one of the few manufacturers to supply. Of course this could not have been known by Taiwanese policymakers at the time of the technology transfer. However, an important aspect to point out is that it was enabled due to the fact that it could increase the value of the users' existing resource structures, and thus providing opportunities for Taiwanese companies to become suppliers of semiconductors. Furthermore, an important reason for ITRI choosing RCA was the extensive support program the company offered. RCA provided a complete production technology and training for 37 Taiwanese engineers at RCA's US laboratories for a year. Since the technology transfer also entailed extensive personnel training, ITRI had a large number of trained engineers by the mid-1970s. In addition RCA helped ITRI set up a fully operational semiconductor production facility. RCA was willing to help ITRI set up a production facility since the technology was considered obsolete and the company was about to withdraw from the semiconductor field. The production facility that was established was fully functional within a year after the signing of the contract with RCA. As the technology transfer was accompanied by interaction related to other complementary resources, capabilities and knowledge of semiconductor development could be built up. However, as mentioned in the case, this did not lead to any major achievements commercially. But the explicit goal of ITRI was not primarily to make economic returns on the investments made, at least not at that stage. The main aim was to learn how to develop and produce semiconductors. Until the 1980s the capabilities and technologies of the local structure had already been built up through a large number of resource combinations with existing developing and producer-user structures, where the interface with RCA was quite substantial and important.

3. Interface with established producers

Besides RCA, other foreign semiconductor companies were not actively collaborating with the emerging Taiwanese semiconductor network, although relationships to multinational electronics companies had already existed since the 1960s. The view of Taiwanese policymakers was that the business units of the foreign companies had positive effects on Taiwan's economic growth but had added little value to the emergence of a home-grown industry. It was not until the mid-1980s that they were considered to have an important role by the Taiwanese government. Nonetheless, it is difficult to separate and neglect the role the foreign companies played before the Taiwanese industry started to grow rapidly in the late 1980s. Although the presence of the foreign companies in Taiwan in the 1960s had no immediate impact on the development of advanced semiconductor technology in Taiwan, it served as an important platform whereby important relationships and commitments came to be established. By the time Taiwanese policy decided to start promote the semiconductor field, foreign electronics companies had been present in Taiwan for over a decade. The relationships which were established between Taiwanese and foreign companies provided knowledge to Taiwanese employees, gave rise to new companies, and set the foundation for the electronics industry (which later became a source of users of Taiwanese semiconductors). Furthermore, established Taiwanese companies also received a share of technologies and business as they were seen as important business partners to the foreign companies. Thus an intricate network of interfaces to producer-user settings had emerged. In this period the local structure had already had extensive interaction with established business structures, which was also inherited by the spin-offs.

What the case indicates is that the organizational interfaces that were created were often not consciously part of an ambition to build up a semiconductor industry. For instance the relationships, developed between foreign electronic companies and the Taiwanese government were built up over decades, starting with the establishment of a foreign-owned electronics industry in Taiwan in the 1960s. The activities to develop semiconductor technology as well as business in the 1970–1980s were thus undertaken in an environment where major global suppliers of semiconductors were already active in the Taiwanese economy, as producers of electronic appliances. As relationships between Taiwanese companies, policymakers and the foreign companies were established there was continuity in their interaction. However, it was after many years of infrastructure build-up and commitment from the Taiwanese government that the foreign companies present in Taiwan eventually became interested in the Taiwanese semiconductor industry.

4. Interface with UMC and TSMC

Following the establishment of ITRI the local resource structure became incrementally more advanced and was on par with world standards in the mid-1990s. This was in part due to the structure of local companies emerging in the 1980s. ERSO had improved the CMOS technology in the production facilities created with the help of RCA. Eventually a part of ERSO's production facility was spun off into a new company, UMC. Later ERSO's

VLSI production facility was spun off laying the foundation to TSMC. Not only were these two spin-off companies the first two Taiwanese producers of semiconductor technologies, today they are also the two largest semiconductor foundry companies in the world. When UMC was spun off from ITRI it inherited both a production facility and its first customer. The first Taiwanese semiconductor company became a producer of reliable but non-advanced semiconductors, catering mainly for small South-east Asian electronic companies. This business idea changed when Philips became interested in a joint venture with ITRI. The creation of TSMC had a profound effect on the Taiwanese semiconductor industry, and also the global semiconductor business. The birth of the semiconductor foundry and Taiwan's flagship company TSMC was the result of the interaction between ITRI, Philips and the Taiwanese government. These organizational units had at the time goals which were commensurable. The Taiwanese government wanted to create an industry and ITRI had reached a stage where it could spin-off a part of its facilities. For Philips there were clear business opportunities from outsourcing its production. Hence, Philips transferred technology, know-how, a cross-licensing portfolio, as well as legitimacy to the new start-up (each resource being instrumental to the development of the TSMC). But perhaps more important was the fact that TSMC had one of the largest electronics companies in the world as its customer from the start. This allowed TSMC to upgrade its manufacturing technology and skills in a short amount of time. Becoming a supplier to a large and advanced user not only proved beneficial in upgrading the technology of TSMC but it also drew the attention of other large electronics companies such as Intel and Texas Instruments to mention a few that later also became customers of TSMC.

5. Interface Philips and other advanced users

A major reason why advanced semiconductor companies were not initially customers of Taiwanese semiconductor products is quite simple. The Taiwanese companies did not offer any complementary resources which they needed. Most of these advanced companies were fully vertically integrated in terms of design and production, and had no interest in what was being developed at ITRI. The only part of the production which was outsourced was the testing which did not require any advanced capabilities. Thus in the beginning ITRI's production catered to a largely "low-tech" segment of the semiconductor market. ITRI and later UMC was not regarded as a threat by the top semiconductor manufacturers, neither did they produce anything of economic value for them. This changed with the idea of semiconductor foundry and the opportunity to create an external supplier. The established semiconductor companies were not interested in another company that could develop advanced technologies. Instead the solution that was created, and which provided a complementary resource base to these advanced users' existing resource structures, was a Taiwanese company TSMC. The business idea was to supply advanced semiconductors based on users' specifications. This business was not a result of ITRI creating a high-tech production plant and then finding customers. The demand was created through interaction between the ITRI and an established business structure. For example, the business relationship between TSMC and Philips had a long history. Philips had been present in Taiwan since 1961 and over the years the commitment had come to grow stronger. When the Taiwanese government searched for a partner to form TSMC, Philips was a potential candidate. Other companies that were approached were Intel and Texas Instruments, all advanced semiconductor companies, but in the end Philips turned out to be the only serious candidate. The reason was not only because it had the resources, of importance was also the company's long-term dedication to Taiwan. It must be taken into consideration that TSMC was an unproven business idea and the burden of proof was on ITRI. The other companies were just not convinced of TSMC's potential. However, for Philips the incentive to invest was to increase the value of its already made investments abroad and in Taiwan. The company also wanted a supplier for a set of VLSI technologies, the leading standards at the time. The idea was something which quickly became embedded into the existing structure of related producer-user interfaces. Later on TSMC also became a major supplier to other semiconductor companies such as Intel and Texas instruments among others.

Table 2: Summary of resource interfaces

1	ITRI & TAC	ITRI created from a directive from Taiwanese policy with mandate to establish an industry and undertake research in the field of semiconductors. Established with the help of TAC which consisted of semiconductor professionals from abroad provided ITRI with direction, knowledge and contacts.
2	RCA & Technology	RCA not willing to license an advanced technology but saw a chance to make some revenue by licensing out an obsolete technology. Provided ITRI with knowledge, support, facility, training and a mature technology which already had established user-producer interface. Policy wanted advanced technology, acquiring the mature technology within the realms of the government budget.
3	Electronics producers	Multinational producers already in Taiwan during the 1960s, wanted to take advantage of low cost production. Government policies of import substitution and export promotion provided incentives for these companies to set up shop on Taiwan. Important relationships and commitment from the established producers created, especially with Philips. Also helped establish a local electronics business network, although not a direct goal of Taiwanese government.
4	Spinoffs	Government supported the spinoffs, UMC and TSMC. TSMC was created through the combination of spinning off ITRI's VLSI production facility and the technological know-how from Philips. This resource combination brought forward a new production process, semiconductor foundry, a novel idea which was enabled partly due to the support of the Taiwanese government. It later in turned out to become a money-earning business model for both TSMC and other Taiwanese businesses.
5	Advanced users	Advanced users not interested in Taiwanese semiconductor technology or products. Taiwanese policy not able to control or influence these actors. After a complementary resource was established base (TSMC) the advanced users were willing to cooperate with Taiwanese semiconductor companies.

Discussion and conclusions

In this article the purpose has been to increase the understanding of forced network creation in the context of resource interaction, and in relation to the role of public policy. The understanding reached from this study will be discussed through three propositions which have been identified in earlier studies of resource interaction (Håkansson & Waluszweski, 2002, 2007; Waluszewski et. al., 2009; Shih, 2009 among others). The propositions are as follows: 1) *Resources are combined over multiple spaces and times*; 2) *New resources are always combined with existing resource structures* and; 3) *The economic value of any new resource is closely associated with how it can embedded in a using structure.*

1. Resources are combined over multiple spaces and times

As has been highlighted in the analysis it is not single events at a certain time or place which triggers the formation of new industries. What this study illustrates is that the emergence of the Taiwanese semiconductor business network was the result of both planned and unplanned combinations of various resources over an extended period of time and in different places. The emergence of a semiconductor business network happened without following a linear path with first R&D, then production and finally use, at consecutive separate stage. Rather use-production-development happened concurrently, where developing structures emerged in relation to already existing using and producing structures. With the assistance of established knowledge sources, it took more than a decade to establish research and development capabilities. A producing structure was built up over an even longer period with close contact to users. These users had an established presence in Taiwan already in the 1960s and, although they were not active at the time, resource synergies were created. The emergence of a Taiwanese semiconductor business network was thus a result of combinatory efforts stretching over at least three decades and shows the importance of the close ties between developing, producing and using structures.

2. New resources are always combined with existing resource structures

As discussed above a factor for value creation was the ability of different actors to take advantage of what had already been created in other resource structures both locally and internationally. The Taiwanese government's effort to create space for Taiwanese organizations and companies in an international network, covering development, production and use of semiconductors, was a key factor for the emergence of a business network. In particular the connections to established producer-user settings were imperative in the development. For instance the subsidiaries of the foreign companies provided local employees and suppliers with education, knowledge and technology. Already from the 1960s new local companies were started in the wake of the foreign investments. What was in creation was the emergence of a producer-supplier network which continues until today, where semiconductors became an extended business activity due to already established business relationships. These interfaces brought forward knowledge and also various solutions which could benefit the Taiwanese semiconductor business network. Thus the notion that there is always something to build on is imperative when formulating viable public policies to develop business networks.

3. The economic value of any new resource is closely associated with how it can embedded in a using structure

From the empirical account it is also evident that the value of any new resource is strongly related to how it can be embedded in using structures. Although there were interfaces to advanced using structures already before the Taiwanese semiconductor business network emerged, multinational semiconductor companies did not become customers of Taiwanese made semiconductors until the early 1990s. Why the advanced multinational companies eventually became customers of Taiwanese semiconductors products was to a large extent dependent on the possibility to create additional value of their already made investments. What happened in the Taiwanese case were Taiwanese companies becoming part of a global semiconductor supply chain. By concentrating on only a part of the production chain and becoming suppliers of semiconductors to advanced using structures, the Taiwanese companies were not competing with their customers and did not risk eroding the value of their investments. Instead they complemented the resource structures of the advanced using structures.

Policy implications

What can the above discussion tell us about forced network creation and what implications are there for policy? What the analysis of the resource interfaces in the Taiwanese semiconductor business network has portrayed is that the emergence of the network came about through interaction between both established and new resources over several decades and geographical borders. The industry was not an instant economic success nor did it just surface in a setting with tabula rasa antecedents. Development of semiconductor technology occurred in close relation to already existing producer-user structures and the closeness functioned as a catalyst to the emergence of a semiconductor business network in Taiwan.

As is evident from the empirical account the different actors in the network that emerged had various goals which often were not compatible. But Taiwanese policy was an important and skilful network actor. For example Taiwanese policymakers assisted in establishing and creating interfaces to various organizational and physical resources, in particular to existing producing-using structures. Policy was also innovative in creating new organizations, empowering professionals with experience to lead the way in development and allowed the policy-supported institutions to take new directions. What seemed to be an essential factor is the flexibility through which policy acted, a trait which does not always seem to go well with pro-active government intervention and guidance. Thus the notion of Taiwanese policy creating and controlling the business network omits several important empirical conditions in the emergence of the network. An important factor seems to be the reliance on an existing network of resources, locally and internationally, within and beyond organizational borders. Taiwanese policy was far away from controlling this larger network, especially the users. Furthermore the ability of other network actors to take advantage and create value of already embedded resources, independent of policy's ambition should not be downplayed.

What can policy then actually do? Governments can support business networks through funding and infrastructure build-up. Nonetheless, this does not equal control of the network, or controlling the goals of a larger number of actors within the network. As this study suggests policy can also facilitate the processes through which relationships are established and interfaces are created. Especially how to create persisting interfaces between developing, producing and using structures should be of higher importance. Furthermore promoting flexibility and providing institutional stability are measures which policy should actively pursue.

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