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Industrial Structure, Technical Change, and the Role of Government in Development of the Electronics and Information Industry in Taipei,China

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FOREWORD

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CONTENTS

ABSTRACT

Taipei,China has achieved remarkable development and export performance in its electronics and information technology industry in the past three decades. Starting out as heavily dependent on foreign technology in the 1960s and 1970s, firms in the electronics and information industry devoted considerable technological effort and successfully negotiated the daunting currents of competition to participate in new product development by the 1990s. The industrial structure of the electronics and information industry has evolved from a small- and medium-size enterprise operation into a large-firm operation by the late 1990s, which further facilitated the export orientation of the electronics and information industry. Government adopted selective industrial policies to overcome the problem of market failure and enhanced systemic coordination and cohesive networking. Therefore, the Taipei,China government essentially “made”, rather than ”picked”, the winner of the electronics and information industry in Taipei,China.

I. INTRODUCTION

Taipei,China achieved rapid economic development over the past half century. Its gross domestic product (GDP) and per capita income grew in real terms by 44 times from US$1.7 billion in 1952 to US$282 billion in 2001; and over 16 times from US$196 in 1952 to US$12,678 in 2001, respectively. This is all the more remarkable as the spectacular growth rates were achieved under conditions of low income equality until 1980. In addition, unlike the Republic of Korea, which succumbed to the Asian financial meltdown of 1997, Taipei,China's GDP declined by only 2 percent in 1998 and achieved positive growth in 1999-2000 (Table 1), just before 2001 when Taipei,China experienced its worst economic recession in the past 30 years.

TABLE 1
TRENDS IN THE ECONOMY OF TAIPEI,CHINA,
1960-2001

	1960	1970	1980	1990	1996	1997	1998	1999	2000	2001
GDP (US$ million) at current prices	1,718	5,670	41,418	160,173	279,611	290,201	267,154	288,697	310,134	282,400
Per capita GNP (US$)	154	389	2,344	8,111	13.225	13.559	12,333	13,248	14,216	12,678
GDP growth rate (percent)	6.3	11.4	7.3	5.4	6.1	6.7	4.6	5.7	6.0	- 1.9
Gross national savings as percentage of GNP (percent)	17.8	25.6	32.3	29.3	26.7	26.4	26.0	26.1	25.2	24.03
Unemployment rate (percent)	3.98	1.70	1.23	1.67	2.60	2.72	2.69	2.92	2.99	4.57
FDI (US$ million)	15	139	456	2,301	2,461	4,267	3,739	4,231	76,079	51,285
Total exports (US$ million)	164	1,481	19,811	67,214	115,942	122,081	110,582	121,591	148,321	122,900
Total imports (US$ million)	297	1,524	19,733	54,716	102,370	114,425	104,665	110.690	140,011	107,240
Trade balance (US$ million)	-133	-43	78[1]	12,498	13,572	7,656	5,917	10.901	8,310	15,760

[1]The trade balance of US$78 million in 1980 may mislead the readers, since it was just a single event. The trade balance was US$1,660 million in 1978; US$1.329 million in 1979; and US$ 1,412 in 1981.
Source: *Taipei,China Statistical Data Book* (Council for Economic Planning and Development, 2001).

Taipei,China's rapid economic growth was spearheaded by industrialization. Manufacturing production, which accounted for 84 percent of industrial production in 2001, expanded by 130 percent (in real terms) over the period 1986-2002. The electronics and information industry[1] grew in real terms by the largest margin, expanding by 410 percent. The share of the electronics and information industry in manufacturing production rose from 16 percent in 1986 to 37 percent in 2001, which accounted for about half of total exports in 2001. Taipei,China has become the fourth largest information hardware producing country in the world since 2000.

Taipei,China's achievements at the macro level have been well recognized in the development literature (see World Bank 1993). However, there is still a lack of consensus over how rapid export expansion and structural change was achieved. Two dominant but contradictory explanations of the rapid growth performance of Taipei,China's firms continue to enjoy strong currency. The first argument points to the allocative role of markets, which posits that small and medium enterprises (SMEs) cashed in on the scale effect offered by export markets and efficiency improvements driven by competition (Krueger 1981, Balassa 1982). The second argument emphasizes the importance of governing instruments imposed on markets (Wade 1990, Lall 1996), which explained that selective interventions by government assisted firms to overcome market failure, and enjoy the discipline of the market to stimulate capability building in local firms (including through acquisition of foreign technology) to sustain export expansion.

This study attempts to re-examine Taipei,China's export and structural change performance by focusing on the electronics and information industry in general, and the computer and peripherals subsector in particular. The study analyzes how selective interventions and market forces stimulated technological capability building in private companies and facilitated the development of the electronics and information industry in Taipei,China. It also discusses the role played by government to provide a better understanding of the dynamics of export performance in firms. This paper is organized as follows. Section II describes the general structural change in Taipei,China's economy and the importance of the electronics and information industry to economic growth. Section III explains the development of technological capabilities in private companies and the electronics and information industry as a whole. Government policies are discussed in Section IV. Section V presents the conclusion.

II. STRUCTURAL CHANGE AND ECONOMIC TRENDS

Taipei,China's industrial development underwent two major stages. The first stage was import substitution, which was the major industrial policy until the late 1950s. Quota and tariff barriers were used extensively to protect the domestic market to promote import-substituting industries. During this period, Taipei,China's economy was characterized by labor-intensive and traditional industries. The second stage occurred after 1960, when Taipei,China reformed its trade policies and began to adopt export-oriented strategies.

[1] The electronics and information industry in this study is defined according to the *Industrial Production Statistics Monthly Report* published by the Bureau of Industry Development, and comprises cable and line, consumer electronics, information electronics (computers and peripherals), audio and video electronics, telecommunications, electronic components and parts, and precision machinery industries.

Rapid economic growth and structural change has transformed Taipei,China's economy substantially over the past four decades. In the 1960s, the agriculture sector was the driving force for economic development, accounting for around 28.5 percent of GDP. Agricultural exports contributed to about 80 percent of total export earnings in the 1960s. The sequential and coordinated implementation of import substitution, and later, export-oriented strategies, led to the industrial sector gradually becoming the main driver of economic growth in Taipei,China. The share of the industry sector increased from 26.9 percent of GDP in 1960 to 45.7 percent in 1980 (Table 2). After peaking at 47.1 percent in 1986, the industry sector's share of GDP gradually declined throughout the 1990s to 30.9 percent in 2001, while the share of agriculture sector shrank to about 1.9 percent of GDP in 2001. The service sector increased its share in GDP from 44.6 percent in 1960 to 54.6 percent in 1990, and to 67.2 percent in 2001 on the back of strong growth in the financial, insurance, and retail subsectors. By 2001, the structure of Taipei,China's economy had begun to resemble that of developed economies.

TABLE 2
SECTORAL COMPOSITION OF GROSS DOMESTIC PRODUCT, 1960-2001
(PERCENT)

	1960	1970	1980	1990	1996	1997	1998	1999	2000	2001
Agriculture	28.5	15.5	7.7	4.2	3.2	2.6	2.5	2.6	2.1	1.9
Industry	26.9	36.8	45.7	41.2	35.7	35.3	34.6	33.1	32.4	30.9
(Manufacturing)	[19.1]	[29.2]	[36]	[33.3]	[27.9]	[27.8]	[27.4]	[26.6]	[26.3]	[25.8]
Service	44.6	47.7	46.6	54.6	61.1	62.1	63	64.3	65.6	67.2
Total	100	100	100	100	100	100	100	100	100	100

Source: *Taipei,China Statistical Data Book* (Council for Economic Planning and Development 2001).

While the service sector had become the single largest sector by the 1990s, manufacturing has remained the prime engine of growth.[2] Manufacturing production increased from US$95 billion in 1986 to US$219 billion in 2001, accounting for 26 and 81.2 percent of GDP and industrial production, respectively (Table 2). Manufacturing production has enjoyed an average expansion of 10 percent per annum over the past 17 years. Over 55 percent of manufacturing production was exported in 2000, which despite the global recession, only fell to 45 percent in 2001. With a total of US$147 billion, Taipei,China became the 14th largest exporter of manufactured goods in the world in 2000.

[2] For purposes of comparison, this study employs data compiled by the Industry Development Bureau (IDB) in Taipei,China. IDB has regrouped the manufacturing subsector into four major industries, namely, metal and machinery industry, information electronics industry, chemical industry, and basic living and necessities industry. The metal and machinery industry consists of steel, metal products, machine tool, industrial machines, and transportation equipment industries. The electronics and information industry consists of cable and line, consumer electronics, data storage and processing, audio and video electronics products, telecommunication, electronic components and parts, and precision machinery industries. The chemical industry consists of leather and fur products, paper and paper products, chemicals, rubber material, rubber products, and plastic material industries. The basic living and necessities industry consists of food, textile and garment, wood and bamboo product, nonmetal, and other industries.

Taipei,China managed to shift production toward higher value added activities as the economy grew rapidly and production costs rose. The basic living and necessities industry was the largest segment of manufacturing in the 1980s. However, rising production costs—caused by soaring costs of land, labor, and an appreciation in the New Taipei,China dollar (particularly since the Plaza Accord of 1986) and the withdrawal of the Generalized System of Preferences (GSP) in February 1988—drove many of the traditional and labor-intensive industries to the People's Republic of China (PRC) and Southeast Asian countries. The government eased the outward movement of labor-intensive industries following its own aggressive efforts to shift industrial focus to higher value added activities. The government began to build the high-technology and research and development (R&D) environment in the country by building the infrastructure, offering incentives, and strengthening coordination relationships from the 1980s. Hence, a combination of rising production costs and government promotion of the high-tech infrastructure helped stimulate the growth of high-tech industries such as the electronics and information industry, which experienced rapid expansion in the 1980s and 1990s. By 1996, the electronics and information industry had become the largest manufacturing industry in Taipei,China, replacing the metal and machinery industry, which was the leading manufacturing industry from 1993 to 1995. In 2000, Taipei,China had become the 4th largest information hardware-producing country in the world, after United States, Japan, and PRC.

By 1992, the electronics and information industry had become the most export-oriented segment of manufacturing industry, with more than 60 percent of production made for export in the 1980s; the export ratio increased to 74 percent in 2000.[3] Even though the global economy slowed down in 2001, the electronics and information industry still exported almost 60 percent of its production. The electronic and information industry accounted for 51 percent of overall manufactured exports in 2000.

However, the electronics and information industry also accounted for the largest share of manufactured imports in the 1990s, making it an import-dependent exporter. The electronic and information industry accounted for 44 and 58 percent[4] of Taipei,China's total manufactured imports in 2000 and 2001, respectively. Much of the imports constitute a small but expensive list of components, such as central processing units (CPUs) and random access memory (RAM).[5] Nevertheless, the electronics and information industry has managed to achieve positive trade balances (Table 3), even in the global recession of 2001. The declining trade balances over the period 1986-2000 were largely a result of increased liberalization and Taipei,China's reliance on expensive component imports by export-oriented original equipment manufacturing (OEM) firms.

[3] Followed by 60 percent of basic living and necessities related products and 44 percent of metal and machinery industry.

[4] In 2001, Taipei,China's total imports contracted by 24 percent from the previous year, due to the worst recession in Taipei,China's economy in the past three decades. The higher ratio of electronics and information electronics imports in 2001 was not due to the increase of import of electronics and information products, rather it was the result of contraction of overall imports, which made the import of electronics and information products more obvious.

[5] The total cost of CPU and RAM in a computer usually accounts for more than half of the total cost of producing a computer.

Table 3
Structure Change of the Electronics and Information Industry
(percent)

	1986	1991	1996	1997	1998	1999	2000	2001
Electronics Export / Total Electronics Production	64	65	71	74	73	73	74	59
Electronics Export / Total Manufacturing Export	32	31	41	43	45	48	51	48
Electronics Import / Total Manufacturing Import	27	26	33	36	39	42	44	58
Trade Balance*	32	24	21	18	16	15	12	1

*Trade Balance: (Xi-Mi) / (Xi + Mi)
Sources: *Monthly Report on the Status of Manufacturing Sector* (Industry Development Bureau 2002).

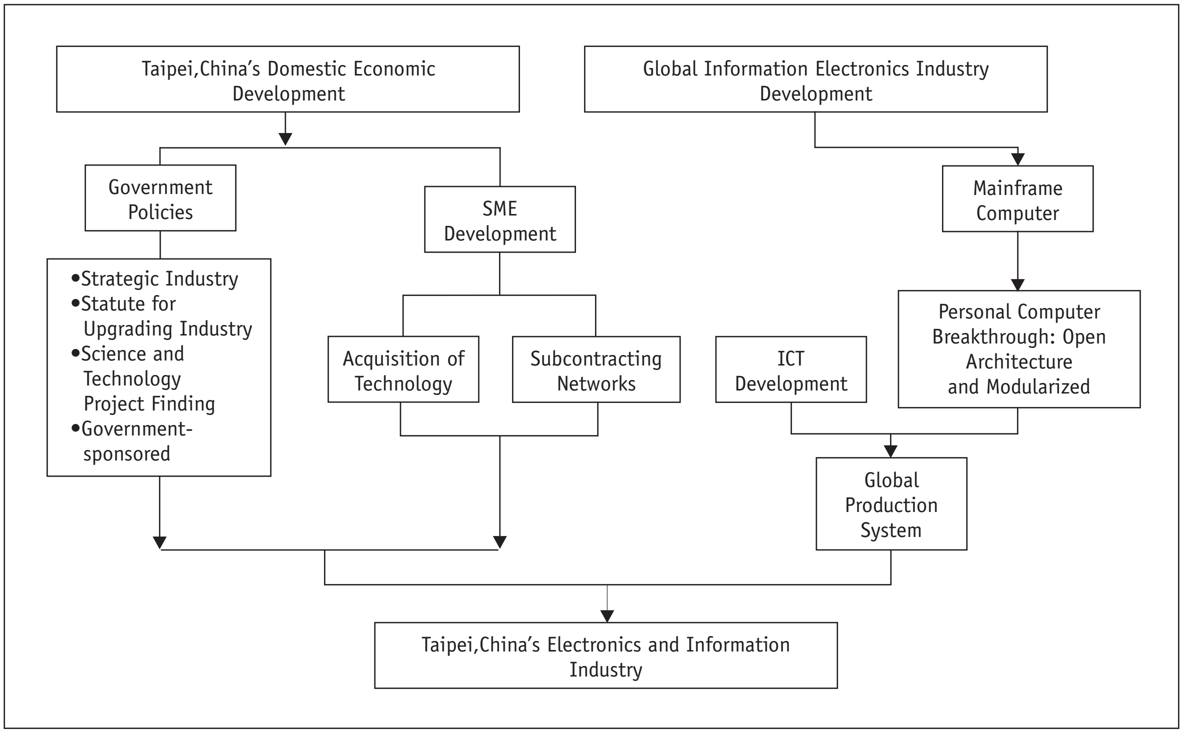
III. STRUCTURE AND GROWTH OF THE ELECTRONICS AND INFORMATION INDUSTRY

Figure 1 presents a taxonomy explaining the dynamics of the development of Taipei,China's electronics and information industry. Taipei,China's economy is basically built on an industrial structure driven by SMEs, making it ideal for subcontracting to evolve as an efficient method of production. Taipei,China's unique decentralized production structure, fostered through strong interfirm production and institutional networks, has offered the market flexibility and the scale and scope necessary to achieve high efficiency.

The introduction of the personal computer became a major watershed in the development of the electronics and information technology industry in Taipei,China. The personal computer transformed manufacturing coordination as its open architecture and modular design encouraged intense differentiation and division of labor. It facilitated the production of each of the computer components and parts separately by different manufacturers as long as they followed the same specifications. This development broke the traditional systems associated with vertical integration. The shift from mainframes to personal computers accelerated outsourcing by multinational companies.[6] From scattered moribund assembly operations, the electronics and information industry production dynamics evolved into well-defined global value chains with subcontractors increasingly playing an active role in the manufacture of components and assembly of computers by the 1990s. Tatung, one of the major electronics appliance producers in Taipei,China, is a typical example of a local information technology firm that generates much of its profits from subcontract operations for foreign multinational companies.

[6] See Rasiah (2002a, b) for an explanation of the advantages of differentiation and division of labor involving the electronics industry.

Figure 1. **Development of Taipei,China's Electronics and Information Industry**



The successful insertion of Taipei,China's firms in global electronics and information technology value chains was also greatly supported by selective interventions by the Taipei,China's government. Government policy was particularly important in stimulating firms' participation in technological upgrading and R&D activities. The government adopted policies that are complementary to its SME-centered industrial structures and cultivated the needed technological capability. The flexibility enjoyed by small size helped Taipei,China's firms to harness the advantages of scope offered by the information electronics global production chains. Taipei,China's firms have upgraded their technological capability from OEM and are now particularly famous as major original design manufacturers (ODM) in the global information electronics industry.[7] Some firms—e.g., Acer—have even managed to become successful original brand manufacturers (OBM),[8] though their numbers are much smaller.

[7] OEM production refers to the operation in which buyers subcontract out the manufacturing of products to other companies. The subcontractors then follow the product design and specifications provided by the buyers and produce the products. ODM production refers to the operation in which subcontractors receive only product specifications from their buyers but take care of all other technical requirements including product design.

[8] OBM production refers to products manufactured under a firm's own brand name.

A. SMEs and the Vertically Disintegrated Industrial Structure

The SME characteristics of Taipei,China strongly facilitated the growth of OEM/ODM manufacturers (technological advancement will be discussed in the following sector). In 1996, Taipei,China had 154,675 firms in the manufacturing sector, a 10 percent increase from 1991,[9] of which 98 percent had fewer than 100 employees, 70 percent less than 10 employees, and 21 percent more than 10 employees but fewer than 30. Overall, 91 percent of firms had fewer than 30 employees. Companies with more than 500 employees accounted for only 0.26 of the total number of firms.

Under the policy to promote exports in the 1960s and 1970s Taipei,China's export of traditional products grew quickly, and orders from foreign buyers flooded the domestic market. The small size nature of the firms made the filling of orders, especially large orders, difficult. At the same time, the scope of the technology also encouraged strong differentiation and division of labor. As a result, Taipei,China's firms began to specialize and achieve horizontal integration.[10] While the large number of firms helped support large-scale production, their small size offered firms the flexibility to better handle fluctuations in demand. Hence, foreign MNCs increasingly outsourced several stages of the value added chain to Taipei,China's OEM firms.

It is difficult to establish precisely when Taipei,China's unique SME structure emerged. Nevertheless, the typical family-owned firms formed the basic root of Taipei,China's firms. SMEs were mainly engaged in garment and metal tooling activities from the 1960s. These industries were modernized and expanded sharply in the 1970s; e.g., fashion shoes (see Hsing 1999); garments (see Shieh 1991); bicycles (see Chu 1997); and machine tools (see Amsden 1985). The small size advantages of subcontracting activities—especially involving components associated with short product cycles as in the electronics and information technology—made it ideal for its evolution in Taipei,China. In the 1970s, the system also facilitated the development of other export-oriented industries such as calculators, telephones, and tape recorders; in the 1980s, it provided the underpinnings for the development of the personal computer and peripheral industries.

1. Firm-level Dynamics

a. Specialization based on core competence

Small firms generally group together horizontally and vertically along the value added chain, so that the sector or the industry as a whole achieves the required scale and scope. For example, the manufacturing of semiconductors can be broadly divided into five major stages, namely, design, masking, fabrication, assembly, packaging, and testing. Generally this has been considered as comprising a highly integrated business. In Taipei,China, however, individual firms in the semiconductor industry usually specialize in only one stage (Figure 2). This has nothing to do with the size of the company; the company could be very large in terms of number of employees hired or sales volume achieved,

[9] **DGBAS [SPELL OUT]** has conducted a national survey on business and commerce every 5 years since 1980. The most recent survey was conducted in 2001 and the results will be published in December 2002.

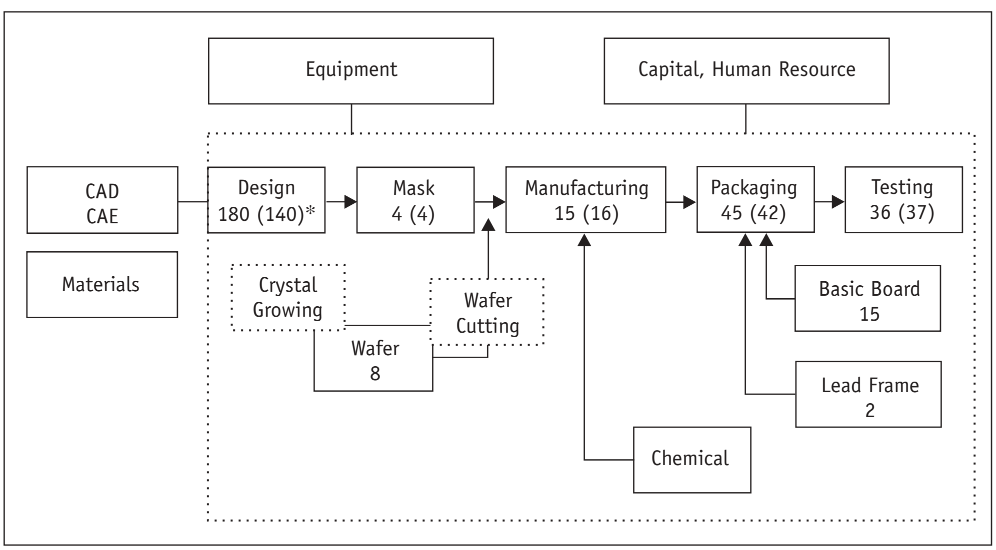
[10] Appendix Table II explains how subcontracting works in Taipei,China's vertically disintegrated industrial system.

but it only specializes in one of the production stages along the production chain. For instance, Taiwan Semiconductor Manufacturing Corporation (TSMC) is the largest semiconductor company engaged in contracted chip production (IC fabrication) in the world, yet it does not design or sell chips. Figure 2 presents a clear picture of the vertically disintegrated structure of the semiconductor industry in Taipei,China, which comprised a total of 315 firms in 2001. Each production stage involves a number of firms that specialize in a few tasks, with none having integrated operations. Taipei,China's semiconductor industry, like many other industries in Taipei,China, is much more reliant on the market mechanism than command governance from large hierarchies or vertical structures typified by Japanese and Korean firms. Intense differentiation and division of labor but with efficient inter-firm coordination helped Taipei,China's firms achieve strong systemic synergies to effectively compete globally.

b. *Low entry barriers*

Firms in a vertically disintegrated industrial system need only a small amount of up-front capital investment to enter the industry (Levy and Kuo 1991). Off-peak demand is easily met from further subcontracting, however, small size offers the flexibility for firms to step up and step down production to meet reasonable fluctuations in demand. Capital utilization rates in small firms are generally quite high. Hence, the subcontracting network relieves small manufacturers of large fixed costs, which consequently eases entry and exit. The decomposition opportunities generated by such an industrial organization stimulates rapid entry when demand increases and the reverse when it falls. The result is a "bee-like" swarming of market entries when the industry is experiencing rapid growth (see also Kawakami 1996, 29). Taipei,China's unique industrial structure helped small firms take advantage of the proliferation of vertically disintegrating activities in transnational firms following the birth and expansion of the personal computer industry.

Figure 2. **Value Chain of the IC Industry, 2001**



* Figures in parentheses are 2000 figures.
Source: Industry Development Bureau (2001).

Rapid technical change (product and process) increased flexibility in Taipei,China's firms. Low entry barriers and the horizontal specialization in technologies where scope rather than scale is important, stimulated SMEs to jump industries depending on the nature of demand. Levy and Kuo (1991, footnote 16) observed that Taipei,China's firms specializing in manufacturing products for the export market, particularly those with a short life cycle, have continuously turned over their product lines depending on the market situation. Taipei,China's firms could be producing any or all of related products using similar production technologies, e.g., electronic calculators, modern telephones, and electronic toys.

Information technology production in Taipei,China experienced differentiation and division of labor both vertically and horizontally. They can be vertical (e.g., a final-product assembler subcontracts the work of component assembly to other firms), or horizontal (e.g., a final-product assembler subcontracts part of the assembly work to other final-product assemblers). Manufacturing is so dispersed in Taipei,China that it takes place in formally established firms to households that perform subcontract work involving the stitching of buttons on dresses. Taipei,China's intensely dispersed firms can respond quickly to the quantitative and qualitative changes in market conditions.

c. Interfirm independence

Extensive engagement in subcontracting helped Taipei,China's firms retain strong interfirm independence—both collaboration and competition that typify industrial districts—so that costs-associated institutional rigidities that arise from market-driven restructuring are minimized. The small firms can easily amortize investment in plant and machinery as they have wider markets to service.[11] Subcontractors have a high degree of independence as they do not lock into any large industrial group. An individual firm could be a subcontractor to a number of companies, and or export to the international market at the same time. This is contrary to the situation in Japan and Korea, where several subcontractors are locked into specific large companies. While the exclusive purchasers of the *chaebols* in Korea provide their subcontractors with technological and market support, the independent subcontractor in Taipei,China enjoys flexibility and competition to introduce new technologies, diversify markets, lower production costs, and even jump industries. The exposure to greater market competition has also forced subcontractors to upgrade their technological capabilities continuously, which has helped raise firm and overall industry efficiency levels. Even in high-tech activities, contrary to the perception that large firms invest more in R&D, Wang (1999) reported that in 1993-1995 half of the patents approved in Taipei,China for the information electronics industry were acquired by SMEs.

Thus, Taipei,China's vertically disintegrated industrial system has proved ideal for producing products that can be decomposed intensively to appropriate small-size specialization economies. A range of SMEs—from the household single employee to the modern firm—have utilized their capabilities to meet stringent market requirements to participate in global exports. Smooth network cohesion has facilitated quick responses to market stimuli even in the high-tech industry of information technology.

[11] Rasiah (1994) traced the early emergence of similar interfirm links in Penang.

2. Industry-level Dynamics

a. Scale Effects Captured by Industry Size rather than Firm Size

Dispersed and open industrial structures facilitated the appropriation of scale economies through smooth interfirm coordination. Firm-level productivity increments in Taipei,China is not possible without interfirm differentiation and the finer division of labor from scale economies enjoyed by industrial clustering. Increasing market size helped stimulate differentiation, specialization and division of labor. For example, PC assemblers have transformed: from the time when the PC industry was small and PC manufacturers were assembling even motherboards initially, to specializing on final PC assembly when sufficient scale was reached. The exponential growth in PC demand offered firms the scale for specialization in motherboards and others in final PC assembly. Increased industry-level scale, specialization, and differentiation raised the productivity of motherboard manufacturing.[12] In this case, the interfirm division of labor substituted for the division of labor within integrated firms. Therefore, increasing returns to scale was appropriated at the level of the industry rather than the firm (see Chang and Chen 2001).

b. Strong Interpersonal Relationships

The fluidity and ease with which firms entered and exited production in Taipei,China has also raised high risks associated with market fluctuations. The room for breaking contractual as well as tacit obligations—both orders and employment assignments—is high in the dispersed industrial structure of Taipei,China. Job-hopping made high labor turnovers a big issue in its vertically disintegrated industrial system. Nevertheless, interfirm friction from the constant interfirm movement of labor has been kept to a minimum through interpersonal relationships, which was strengthened in the first place by their very movement (Hsing 1999). The strong social network in Taipei,China has served as one of the most valuable sources of information and collaboration between individuals, companies, and institutions. Trust and cooperation at the industry level has become strong in the sharing of information involving not just factors of production, e.g., labor and finance, but also market trends and technology.

The capacity of Taipei,China's integrated interfirm networks to appropriate scale synergies at the industry level has helped firms avoid the limitations associated with vertical integration. Strong interpersonal relationships helped strengthen subcontracting networks, offering a solid platform for new firm creation. Interpersonal interactions have been a major driver of interfirm links in Taipei,China. Interpersonal relationships helped complement markets to overcome the risks associated with volatile fluctuations in demand. The strong interpersonal relationships helped reduce "transaction cost" and narrow the so-called "agency gap" by lowering "agency cost" (see Coase 1937, Richardson 1972, Williamson 1985, North 1987). Taipei,China's socially integrated division of labor helped reduce the moral hazard and free rider problem.

[12] The higher degree of specialization results in workers in production lines carrying out fewer production tasks, but repeating them more often than in a less specialized environment. The cumulated learning then contributes to the overall productivity increase.

B. Acquisition of Technological Capability

Lall (1996 and 2001) made an interesting argument that countries need to develop their technological capabilities to be able to sustain export competitiveness. Taipei,China is an excellent example where technological upgrading helped drive rapid export expansion. The early sources of modern manufacturing technology were foreign firms through direct investment and licensing.

Significant diffusion of foreign technology to local firms took place in Taipei,China. Lin's (1986) study on cathode ray tube (CRT)-related consumer electronics industry found that the manufacturing capability of PCs and peripherals, such as monitors and computer terminals, originated from the manufacture of color televisions (CTVs) in the 1970s. Products like CTVs, PCs, and peripherals all used CRTs as the major component in their manufacturing and relied heavily on assembly technology. The assembly of radios and black and white TV sets in the 1960s by foreign, particularly Japanese manufacturers, laid the foundation for technological capability building in the industry. Modern manufacturing technology was developed only since 1969 when Japanese joint ventures started producing CTVs in Taipei,China.[13] Gradually seven foreign subsidiaries and 11 local manufactures (through licensing from Japanese companies)[14] joined in production. The following three cases of technological development illustrate how CTV and information electronics manufacturers acquired their manufacturing capability.

1. Acquisition of Production Knowledge and Technology

In the 1970s, Japanese manufacturers transferred only manufacturing technology—not design technology—of CTVs to Taipei,China.[15] The transferred manufacturing technology covered three broad technical areas of CTV production: (i) assembly line set-up, (ii) machinery and equipment adaptations to meet changing production demands, and (iii) methods for functional and reliability testing and quality control. The diffusion of these three key manufacturing technology was critical in transforming capacity of Taipei,China's firms to launch and manufacture export-quality consumer electronics products.

In the 1970s, Japanese CTV manufacturing technology was based on large-scale assembly line production,[16] high degree of mechanization,[17] and very fine labor division on production procedures. To transfer the technology to Taipei,China, Japanese technology suppliers had to adapt the technology

[13] Since the design of radio and black and white TV in the 1960s still employed vacuum tubes, their production relied heavily on wiring; while CTVs used transistors, thus, production applied printed circuit boards, the basic components for modern electronics products.

[14] Prior to 1984, Taipei,China imposed high tariffs on the import of CTVs, and completely banned the import of Japanese-made CTVs to protect the domestic CTV industry. However, no other protection measure was taken to stimulate the development of computer and peripherals industries.

[15] Since manufacturing technology showed Taipei,China's manufacturers how to produce CTVs, but design technology gave Taipei,China's manufacturers the ability to design new color TV and other related products. The possession of the design technology provided Taipei,China's manufacturers with a much larger degree of technological independence—something that technology suppliers usually do not like to see.

[16] This was 70 times bigger than that in Taipei,China.

[17] In the 1960s, Japanese manufacturers used machines to replace labor in their production process, but at that time machines were still operated by labor and were not yet automated according to today's criteria.

to the Taipei,China's manufacturing environment with its smaller production scale, relatively labor-intensive production requirement, and differently trained workers. To ease the process of technology transfer, Japanese firms dispatched engineers to local plants to assist with the setup of production lines and the installation of machinery and equipment. Taipei,China's firms also sent engineers to the plants of Japanese technology suppliers for training. However, despite efforts to adapt to Taipei,China's dispersed industrial structure, the transferred technology was still developed according to Japanese industrial conditions and the layout of the transferred production line was arranged according to the Japanese industrial engineering (IE) principle of standard time and movement.

Taipei,China's firms absorbing Japanese technology adapted and transformed it to suit their own unique dispersed framework through intensive and continuous learning, appraisal, and reappraisal. Recourse to Japanese technology suppliers was always open because of the contractual obligations. However, reliance on Japanese technology only got Taipei,China's manufacturers to a certain stage in the technology ladder. Local firms had to work on their own to further develop their technological know-how and create their own IE standards. Given the public good nature of learning and the costs associated with initiating learning generic skills, the firms sought broader off-firm training, which helped reduce the costs of duplication.

In the mid-1970s, Taipei,China's manufacturers sent their engineers to the China Productivity Center (CPC), a government-sponsored organization, to attend related courses and acquire basic knowledge on IE concepts and theories, and participate in field studies. Training support from CPC gave Taipei,China's firms basic IE knowledge, which helped renew their interest in developing technology through time-consuming trial and error methods.

Process efficiency improvements can be traced to the use of traditional learning-curve studies involving standard time motion studies. Specialization helped workers raise productivity and time motion studies were used extensively in Taylorist production systems. However, when frequent model changes became a strong feature of Taipei,China's TV market in the 1970s, it resulted in frequent layout changes, and the time motion studies lost their industrial engineering significance.[18] While many manufacturers continued to use time motion studies for reference, they also tried other approaches to estimate learning curves by working on throughput and manufacturing cycle times. For example, some manufacturers took the maximum efficiency of a worker to complete a specific production task as the base to estimate the standard work-time required to complete a task. Others tried different methods to complete a specific production task, and then took the average of all the results as the estimation base. Taipei,China's manufacturers devoted time and effort to repeat the experiments. Combined with their own production experience and the standard time and motion estimates of foreign manufacturers, these manufacturers eventually came up with the set of estimated standard time and motion best suited for local production. Even though the process of developing the IE system was costly and time-consuming, the reward was phenomenal. Based on their own IE system, local manufacturers were able to obtain much more precise cost estimation and thus could do much better production planning to contribute to cost saving in the long run. At the same time, they acquired a much larger degree of technological independence in determining the products that they wished

[18] With frequent changes in layout of the production line, manufacturers did not have enough time to repeat the same operation as the learning curve exercise needed.

to produce, since they could set up the needed production line without asking help/permission from their Japanese technology suppliers.

2. Development of Quality Control Systems

Establishing an efficient quality control system constituted an important part of developing indigenous manufacturing technology in Taipei,China. Local manufacturers engaged in the process of trial and error to develop their quality control system. The strategy was to introduce quality mechanisms in the actual physical production and testing processes as well as in the minds of workers. The concept of quality was built into every step of the production process to ensure a quality product.

Quality control in manufacturing was introduced and improved in three stages. The first stage was in the early 1970s,[19] when local manufacturers just started manufacturing CTVs. They adopted the Japanese concept of quality control, that "good quality was the result of careful examination." The first activity was to examine incoming components to be used for production as soon as they arrived at the factory. Prior to this, manufacturers had extended the "examination activities" to inspection of factories of their component suppliers, and establishment of close cooperative relations with them by helping them solve technical problems and supplying them with quality control concepts and methods.[20] During this period, "failure rate" was used as the criteria to measure quality control. Workers were encouraged to identify problems and take responsibility for correcting them. All manufacturers strived to lower their average failure rate. The basic rationale for quality control was that mistakes could be allowed so long as they could be corrected.

The second stage occurred in the late 1970s when manufacturers began to absorb a much more stringent concept of quality control from Japanese companies: that quality was the result of good production, and everyone involved in production should do the job right the first time. This concept was based on the rationale that making mistakes is wrong; mistakes should not happen in the first place. Along with the adoption of this new concept was the adoption of much higher criteria for quality control. Some manufacturers even set their quality control criteria as below "1 ppm."[21] During this stage, the most difficult task for Taipei,China's manufacturers was to educate their workers to accept the new concept that they should do things right the first time.

To assist workers do things right the first time, manufacturers devoted time and effort to doing their own homework, i.e., they studied the layout of their plants and production lines. For example, they relocated components with similar shapes on the production line to reduce the chance that workers would pick up the wrong component.[22] Factories held seminars and presentations to discuss the adoption of Japanese quality control methods. A manufacturer indicated that:

[19] Prior to this there was no concept of quality control. TV sets were deemed to be acceptable as long as they could function.

[20] This development proved very important in ensuring good component quality and facilitating the development of the component industry in Taipei,China.

[21] "1 ppm", meaning that the acceptable rate of failure should be below 1percent of one million units of production.

[22] This action is not as simple as it seems. Since a production line is arranged according to the function of components not by their shape, to separate components with similar shape could sometimes mean changing the whole production line.

> " Educating workers to be responsible for mistakes they made took 10 years. Another 10 years were required to educate workers that they should do things right the first time."[23]

During the third stage, in the 1980s, manufacturers strived to expand their exporting activities. They upgraded their standard of quality control by absorbing even higher criteria from the Japanese: good quality was the result of good design (both in components and products). To achieve this, manufacturers devoted enormous effort to collecting data on component and product performance, and conducted more appraisal activities to obtain a deeper understanding of the cause of quality failure. In the mid-1980s, for example, when Tatung Corporation became a subcontractor to produce monitors for IBM, it achieved zero defect rates in its production.

By the end of the 1970s, manufacturers had developed their indigenous manufacturing technology and the basic industrial production system. The process of acquiring indigenous capability for Taipei,China's manufacturers was a long and tedious process that involved (i) extensive learning to understand and master transferred technology, (ii) development of new technological systems, and (iii) changes in workers' mindsets. It was a lengthy process that involved a series of technological revisions and modifications, demonstrating how a developing country starts by importing borrowing technology from abroad to finally achieving technological independence.[24] These developments are consistent with the dynamics of technical change in Mitsubishi Nagasaki Shipyard in Japan (1992).

C. Growth and Performance of the Information Electronics Sector[25]

The development of Taipei,China's information electronics sector can be divided into five periods: pioneering in 1979-1983, first wave of expansion in 1984-1988, adjustment in 1989-1992, second wave of expansion in 1993-1996, and relocation of production facilities to the PRC after 1997. In terms of company structure, the information electronics sector comprises four types of enterprises. The first comprises large producers of electronics appliances that started producing consumer electronics products such as CTVs in the 1970s, and PCs and peripherals in the 1980s. The second comprises specialized computer companies that focus only on manufacturing information electronics products like PCs and peripherals. The majority was established in the 1980s when the manufacturing of PCs and peripherals began in Taipei,China. The third comprises SMEs participating in the information electronics sector. The fourth comprises foreign-owned companies.

[23] Based on author interviews (2002). Prior to the production of CTVs, no plant used quality control. Workers considered fulfilling their responsibility as soon as their work was complete.
[24] Kim (1997) had a similar study on Korean technology development.
[25] In 2001, the information electronics sector accounted for 80 percent of total production of the electronics and information industry. Consequently, to understand the development of the electronics and information industry, understanding the development of the information electronics sector is very important. Therefore, for this section, the analysis will focus on the development of the information electronics sector.

It was pointed out earlier that specific structural characteristics had helped shape industrial organization in Taipei,China. Despite the proliferation of R&D activities, the electronics industry is still dominated by OEM assembly operations. Usually in an assembly operation, 70 percent of costs is accounted for by components and parts inputs, about 15-20 percent by labor and overhead, and the rest by machinery and equipment. Assembly operations generally involve relatively low investment in equipment. Therefore, in the short run, as long as the production scale can generate enough revenue to cover the variable labor cost and relatively low overhead and machinery cost, small companies and large companies could coexist in the same industry.[26] Several costs share the scale at the level of industry rather than at the firm level. Assembly operations are associated with a saucer-shaped short-run cost curve that has the same average cost over a range of production quantity (Figure 3). This industrial characteristic also explains why Taipei,China enjoyed a significantly different industrial organization compared to Japan and Korea.

However, scale economies become very critical when firms are engaged in R&D operations, and when OEM producers are specially contracted by large-volume systems integrators and OBM holders. The lion's share of electronics assembly in Taipei,China is suited to a dispersal of production to several firms at any one time so that scale is achieved at the industry rather than firm level. Differentiation both vertically and horizontally in the technical division of labor has helped Taipei,China's firms appropriate the productive synergies associated with specialization and small size flexibility. It will be shown later that electronics firms engaged in R&D and OBM activities, such as Acer and other companies, are large. In addition, there is a tendency for the size of firms to rise in operations where product and process standardization is important because of relatively smaller fluctuations in core technologies, e.g., in stereo set assembly. The development of Taipei,China's electronics industry can be broken into stages by the transition of firms from simple to OEM and ODM and OBM operations.

1. Pioneering (1979-1983)

The pioneering firms in Taipei,China's electronics industry were relatively large-scale operations. As early as 1979, a few large producers of electronic appliances using indigenously developed technological capability began producing monitors and computer terminals.[27] Teco Corporation was the first to participate in international OEM production, which in 1983 received the industry's first order from Honeywell to produce mainframe computer monitors. Teco Corporation was already a large producer of electronics appliances then, and in 2001 was still large and active.

Two noteworthy developments led to the opening and proliferation of small firms in the electronics industry in this pioneering phase. First, Taipei,China experienced a boom in the production of videogame machines in 1980-1982, with exports amounting to US$130 million in 1982 (Kawakami 1996, 25). The high profit ratio of 15-20 percent attracted numerous new producers. Numerous small firms started operations to produce video game machines.

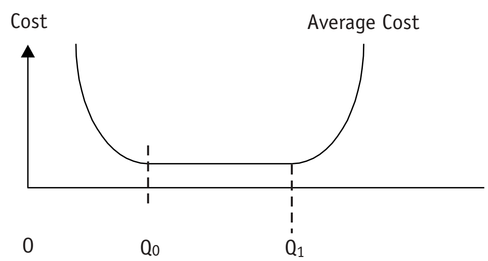
[26] Lin's (1986) study found that small companies produced less than 10,000 CTVs a year, and the large companies produced between 50,000 to 110,000.

[27] Monitors and computer terminals were the first two information products produced by Taipei,China's manufacturers. The manufacturing technology of monitors and terminals was solely developed by Taipei,China's manufacturers, with no technical assistance from abroad.

However, the involvement of youth in video gaming, particularly in videogame gambling resulted in the government banning production in 1983. Majority of the firms then shifted to the assembly of Apple II clones. The experience gained from assembling video gaming machines helped catalyze considerable learning. This was the second development that attracted large numbers of small firms into the electronics industry. The similarity of basic designs between video game machines and Apple clone computers made the transition easy.

Nonetheless, the production of the Apple II clone was also short lived; its production was stopped by legal action taken by Apple Computers against its imitators. Even so, the Apple II surge offered important technological learning experience as it bridged the gap between the technology needed by the information industry and the technological capability that manufacturers accumulated from manufacturing CTVs and other electronics appliances. The banning of both operations also freed talent and facilities that later became part of the industrial resources that facilitated the development of PCs and peripherals in the 1980s. Hence, despite relatively slow growth in productivity, the share of value added per worker of the electronics industry in the manufacturing sector still rose while that of basic and metal and machinery industries stagnated in 1981-1984 (see Figure 4).

Figure 3. **Short-run Cost Curve Associated with Assembly Technology**



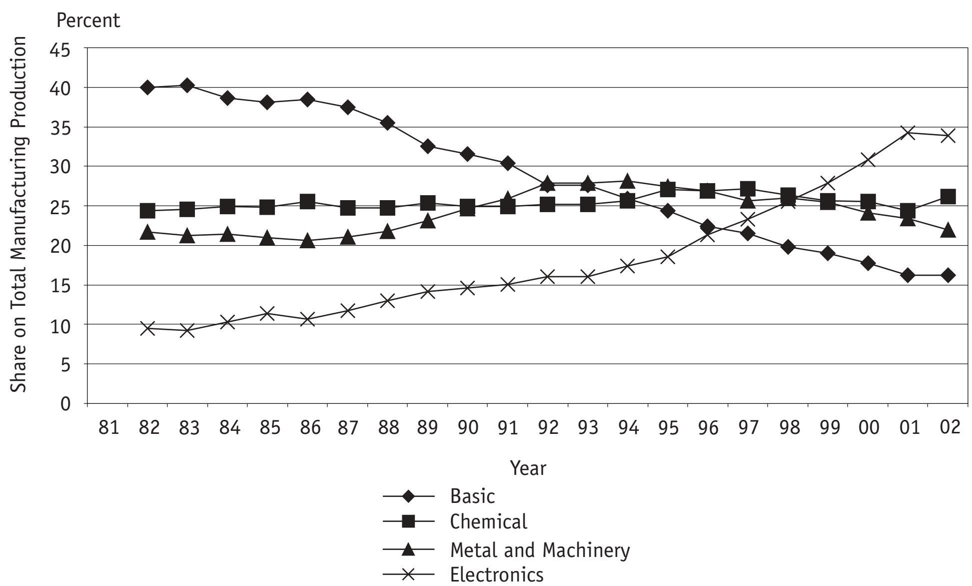
2. First Wave of Rapid Expansion (1984-1989)

The development of the global PC industry helped propel Taipei,China's firms to computer assembly and parts manufacturing activities. The invention of the PC was a technological breakthrough, employing open architecture and modular design, which broke the traditional vertically integrated production of mainframe computers and made outsourcing of components and parts by multinational computer companies possible. Around 1985, Intel developed a new and powerful 32-byte 386 microprocessor that magnified exponentially the computing power of PCs. At around the same time, Microsoft started to sell its new Windows operating system, which greatly enhanced the operative capabilities of computers. The combination of the two resulted in a rapid increase in demand for PCs, which translated into massive outsourcing activities in Taipei,China. Between 1986 and 1988, the average growth rate of information hardware production reached almost 60 percent per year (Table 4). In addition, the share of value added per worker of the electronics and information hardware industry in manufacturing rose sharply, which was matched only by the metal and machinery industry in 1984-1988 (see Figure 4).

The 1980s was a critical period in Taipei,China, for the industrial structure of the information electronics industry evolved during this time. The large number of OEM orders provided Taipei,China's vertically disintegrated industrial structure with the opportunity to have a much higher division of labor and specialization. The information electronics industry gave birth to several species, e.g., PCs, casings, motherboards, power switches, monitors, scanners, keyboards etc. The expansion of the motherboard industry was by far the most representative. In Europe, Japan, and US, motherboard assembly is part of overall computer assembly, and usually a department in a computer company that was not even an integrated electronics company. However, Taipei,China's vertically disintegrated industrial structure enabled OEM firms to specialize and develop the motherboard industry independently from other segments in the value added chain of the information technology industry.[28]

In addition, most of the major computer companies in Taipei,China were also established in 1984-1989. For example, Acer was founded in 1984, Quantum and ASUS opened in 1989. These firms were started by engineering professionals, some of whom had returned to Taipei,China from abroad

Figure 4. **Value-Added Per Worker, Manufacturing Sector, Taipei,China**



to start the new ventures. Rising demand for contract manufacturing helped boost new firm entries in the computer OEM market. Based on their technical background and some understanding of the market, the founders gathered investment funds, often from family members, and established their own businesses. All of them started as small-scale producers. Their technical knowledge and passion for technological development resulted in the introduction of R&D activities, which helped produce

[28] Andy Grove, then president of Intel, visited Taipei,China in 1990 and was surprised to find out Taipei,China had developed the motherboard industry.

Table 4
Production of Information Hardware in Taipei,China and Overseas
(US$ million, percent)

YEAR	TOTAL PRODUCTION OF INFORMATION HARDWARE	PRODUCTION IN TAIPEI,CHINA	PRODUCTION OVERSEAS
1986	2,134	2,134**	—
1987	3,839 (79.9%)*	3,839	—
1988	5,324 (38.7%)	5,324	—
1989	5,484 (3.0%)	5,484	—
1990	6,149 (12.1%)	6,149	—
1991	6,908 (12.3%)	6,355 [92%]***	553 [8%]***
1992	8,390 (21.5%)	7,078 [84.4%]	1,312 [15.6%]
1993	9,693 (15.5%)	7,764 [80.1%]	1,929 [19.9%]
1994	14,582 (50.4%)	9,145 [62.7%]	5,437 [37.3%]
1995	19,543 (34%)	12,683 [64.9%]	6,860 [35.1%]
1996	25,035 (28.1%)	16,758 [66.9%]	8,277 [33.1%]
1997	30,174 (20.5%)	16,536 [54.8%]	13,638 [45.2%]
1998	33,776 (11.9%)	17,760 [52.6%]	16,016 [47.4%]
1999	39,881 (18.1%)	19,819 [49.7%]	20,062 [50.3%]
2000	47,019 (17.9%)	21,548 [45.8%]	25,471 [54.2%]
2001	42,686 (-9.2 %)	24,334 [43.0%]	24,334 [57.0%]

* Figures in ( ) are the growth rate.
** Prior to 1991, the data on production overseas was not available. Since the value of overseas production was not big, the production value in Taipei,China was assumed as the same as the total production.
*** Figures in [ ] are the share to the total production value.
Source: *Information Electronics Industry Annual Report* (various years).

significant technical breakthroughs (Chao 1999). For example, Acer developed the first Intel-based 80386 (32-byte) microcomputer in Asia, ASUS developed the first Intel 486 microprocessor compatible motherboard in Asia, and Quantum made some innovations in notebook PCs. Technical innovations supported the development of these firms to be leaders in their fields in Taipei,China's information electronics industry today. For example, Acer is the largest computer system manufacturer, ASUS is the leading motherboard manufacturer, and Quantum is one of the leaders in notebook PC production. Extensive involvement in R&D activities obviously required Acer, Quantum, and ASUS to expand their operations to become large firms.

While engagement in R&D activities required Acer, ASUS, and Quantum to expand to large-size firms, a large number of SMEs remained as OEM producers supplying manufacturing support to other firms. The SMEs provided a great deal of support to the industry to fulfill the large demand of OEM orders. In 1985, Taipei,China's information industry had 1,709 firms (Table 5). By 1988, in 3 years, the number increased by 160 percent to 4,400 firms. From the member list of the Electronics and Electronic Appliance Manufacturers' Association (TEEMA), for example, Kawakami (1996) found that monitor producers increased tenfold (from 20 in 1984 to 201 in 1990). However, there was still a large discrepancy between the total number of firms in the industry and the number of TEEMA members, despite the fact that not every firm in the industry was a TEEMA member. Kawakami ascribed the discrepancy to the "numerous tiny subcontractors", and attributed the energetic entry of these domestic firms as the major factor contributing to the fast growth of Taipei,China's information industry in the 1980s. In 1985, Taipei,China's information industry reached US$1 billion dollars for the first time and, in 1987, Taipei,China was the largest monitor producer in the world, accounting for more than 40 percent of the global market share (Lee and Pecht 1997, 33).

Table 5
Number of Firms in the Information Electronics Industry, Taipei,China, 1985-1996

	1985	1988	1991	1996
No. of firms	1,709[1]	4,400[2]	4,031[3]	5,559[4]

Sources: [1, 2]: Kawakami (1996, 11) quotes Industry Development Bureau data.
[3, 4]: Chao (2000) quotes the survey data (1991 and 1996) by the Directorate-General of Budget, Accounting and Statistics.

OEM production enjoyed rapid growth during the boom, but as competition rose during the upswing cycle, restructuring became inevitable when the downswing cycle crept in. As with SMEs in general, entry numbers expanded sharply during the upswing, but exit numbers intensified during the downswing. Coordination between SMEs engaged in the production of similar products became extremely difficult as firm numbers expanded sharply (Kawakami 1996, 11). The trust that helped strengthen coordination between SMEs in Taipei,China began to disappear as increasing firm numbers reduced individual firm demand and the consequent cutthroat price competition lowered prices. Matters became worse when the global recession contracted domestic demand in export-dependent Taipei,China.

3. Adjustment (1989–1992)

Overproduction; rising costs of land, utilities, and labor; and the global recession triggered a crisis in Taipei,China's PC information industry by the late 1980s. PC orders from Europe and the US fell sharply between 1989 and 1992. The US PC market contracted by 40 percent in 1990, which severely reduced Taipei,China's PC exports. The recession forced several PC companies to lower prices. For example, Compaq (acquired later by Hewlett Packard), a global PC leader, reduced prices by 30-40 percent to stimulate the sluggish PC market (Lee and Pecht 1997, 33). These developments were exacerbated by the appreciation in the New Taiwanese dollar following the Plaza Accord of 1985. Many traditional labor and resource-intensive producers began to relocate production in Southeast Asia to seek cheaper production costs and better access to foreign markets. PC producers were among the labor-intensive firms that relocated in Malaysia, Philippines, and Viet Nam to take advantage of low labor costs.

Rising labor costs and falling profit margins caused many domestic and foreign firms to fail. Consequently, large numbers of domestics firms (mainly SMEs) exited the PC industry. Acer, Taipei,China's largest PC maker, also laid off workers. The number of firms declined by 10 percent between 1988 and 1991 (Table 5). Most globally known brand names, e.g., Zenith, Commodore, and AmPec, had left Taipei,China, ending the direct participation of foreign manufacturers in Taipei,China. Local companies, especially those begun by engineering professionals in the 1980s, took control of PC manufacturing in Taipei,China. The share of value added per worker of the electronics and information hardware industry in manufacturing continued to rise while that of basic industries continued to fall and that of chemicals stagnated in 1989-1992 (see Figure 4).

4. Second Wave of Rapid Expansion (1993-1996)

Despite the global recession that precipitated restructuring in the information electronics, the large OEM orders still came to Taipei,China during this period. The contributing factor to this rapid expansion was exactly the one that caused the restructuring of Taipei,China's information electronics industry in the first place—the prevalence of low-priced PCs. When Compaq reduced its product prices and promoted low-priced PCs, all other multinational electronics companies followed suit.

Low-priced PCs brought some revolutionary changes into the global information electronics industry. First, it lowered the price of computers as well as that of computer peripherals. This placed pressure on the profit margin of manufacturing of PCs, and related parts, like motherboards, keyboards, and power switches.[29] The result was that the OEM of information electronics products became a specialized business, not just a side business for some computer companies. The pressure on the profit margin of low-priced PCs required that PC production have very accurate controls for cost and quality—only very experienced manufacturers could achieve the level of precision. Second, the demands in producing low-priced PCs made outsourcing a standard business practice, much more than just a means to reduce cost. Some MNCs almost completely outsourced manufacturing operations. For example, Cisco, a leading company in information and telecommunication technology, has contracted out almost 98 percent of its manufacturing operations, keeping only the design and some pilot plants in its headquarters.

[29] Excluding the manufacture of high-tech components, like semiconductors.

Taipei,China's vertically disintegrated and subcontracting-based production system provided the flexibility and efficiency required to meet rising quality standards involving large demand. Taipei,China's information electronics industry has become one "specialized island" that could offer the lowest possible production cost with acceptable quality for OEM production of low-priced PCs and peripherals. Taipei,China's information hardware production, i.e., PCs and peripherals, increased at an average rate of 38 percent per year in the 1990s. Taipei,China became the third largest information hardware producing country in the world in 1995. Taipei,China's share in global markets exceeded half in notebook PCs and monitors, 70 percent in motherboards, and 90 percent in scanners. Value added per worker of the electronics and information hardware industry in manufacturing rose sharply in 1993-1996, almost reaching the share of basic industries (see Figure 4).

TABLE 6
INTERNATIONAL MARKET SHARE OF MAJOR INFORMATION ELECTRONICS PRODUCTS
(PERCENT)

	NOTEBOOK	MONITOR	DESKTOP PC	MOTHER-BOARD	SPS	CD-ROM	SCANNER	NETWORK INTERFACE CARD	HUB	MODEM
1998	40	58	17	61	66	34	84	36	54	34
1999	49	58	19	64	70	34	91	40	66	54
2000	52	54	25	70	74	39	93	—	—	—

Source: *Information Electronics Industry Annual Report* (2001).

Besides bringing in large OEM orders, the introduction of low-priced PCs resulted in some fundamental changes to Taipei,China's information electronics industry. First, it changed the global competitive strategy of the industry by almost halting the development of Taipei,China's own computer brands, as the whole industry focused on OEM operations much more than ever before. Since the low-price strategy was adopted by the global brand PCs, the price difference between the Taipei,China-made compatible PCs (with their own brand names) and the internationally known brand-named PCs shrank from the original US$500-600 to less than US$200 (Huang 1995, 10). The resulting fall in profit margins discouraged Taipei,China's computer manufacturers from pursuing the development of their own brand names; instead they concentrated more than ever on OEM operations. Today, Acer is the only Taipei,China-made brand name prevailing in the global market.

Second, the prevalence of low-priced PCs helped change the structure of Taipei,China's information electronics industry, which used to be SME-centered. Companies in the industry became much larger than before, especially in "final product" industries. For example, there have been about 12 to 15 companies in the notebook PC and server industries, and about 10 to 12 companies in desktop and motherboard industries since the second half of the 1990s. Each of the companies is large and consequently the concentration ratio has increased much faster since the second half of the 1990s.

**TABLE 7
MARKET CONCENTRATION RATIO OF MAJOR
INFORMATION ELECTRONICS PRODUCTS**

PRODUCT	1997	1998	1999
Notebook PC	77.0% (10)*	71.7% (5)	72.0% (5)
Monitor	—	44.5% (5)	46.9% (5)
Desktop PC	—	69.0% (3)	62.0% (5)
Motherboard	—	54.6% (5)	57.5% (5)
SPS	—	82.8% (5)	89.2% (5)
CD-DVD	—	76.5% (5)	72.4% (5)
Case	—	38.6% (2)	45.3% (5)
Scanner	—	62.3% (5)	75.9% (5)
Graphics Card	—	46.0% (5)	52.0% (5)
Keyboard	—	64.1% (3)	77.3% (5)
UPS	—	33.0% (5)	31.2% (5)
Mouse	—	61.5% (3)	62.4% (4)
Sound Card	—	86.2 % (2)	90.0 % (3)
Video Card	—	95.0 % (4)	96.0 %(4)

*Figures in parentheses indicate the number of firms in the concentration ratio.
Source: *Information Electronics Industry Annual Report* (Institute for Information Industry 2001).

The five-firm concentration ratio of notebook PCs and desktop PCs was 72 and 62 percent in 1999, respectively, and that of computer peripherals was also very high (Table 7). The high concentration ratio for the end products of the information electronics industry has a different structure than the one that was SME-centered.

There are several explanations on the change from an SME-centered structure into a large companies-centered one. First is that when the requirement for lower production cost becomes rigorous, it becomes essential to take advantage of scale economies. Companies with larger scale can achieve lower costs more easily. Second, since multinational electronics companies rely heavily on outsourcing the needed PCs and peripherals, individual OEM orders are large. Thus they have imposed much higher prerequisites on their subcontractors' management, technology, and financial situations, as the price they have to pay for failure of delivery by their subcontractors is much higher than before. Consequently, larger companies more easily meet the requirements and thus more easily obtain OEM orders. Third, to reduce operational costs further, multinational electronics companies have started to include their subcontractors in their global logistic mode of production, i.e., subcontractors not only have to produce the products, but also have to serve the role of distributor. Multinational electronics companies have started to ask their subcontractors to establish assembly facilities or distribution warehouses at certain assigned foreign places, so that local marketing agents can go directly to the OEM subcontractors to pick up products to fulfill their orders. This is the so-called built-to-order (BTO) model. To engage in BTO operations, subcontractors have to possess sufficient financial and management capability to establish a worldwide network of distribution warehouses or marketing bases to provide the multinational electronics companies with all-around services[30] (Mai, Wang, and Tsai 2002).

Chau's (2000) study of the changing industrial structure of Taipei,China's information industry supports this observation. He calculated the average value-added of individual firms in different segments of the information industry and found that firm size has been increasing even as early as 1991. Firm size in the segment of components, like semiconductors, expanded the fastest, followed by data storage manufacturing and computer parts manufacturing. The only exception is in monitors, where firm size fell owing to the relocation of production to the PRC.

5. Relocation to the PRC (after 1997)

The overseas relocation of Taipei,China's information electronics production facilities began in the 1980s. At that time, relations across the Taipei,China Strait were still tense, thus relocation was mainly to ASEAN countries. However, only 8 percent of Taipei,China's information hardware was produced overseas until 1991. This began to change beginning from 1991 as the relationship between Taipei,China and the PRC gradually improved. The Taipei,China's government officially permitted Taipei,China's companies to invest in the PRC from 1991,[31] which helped increase investment by the electronics and information industry in the PRC to US$4.8 billion by 2000 (Table 8). The first surge of Taipei,China investment in the PRC took place in 1993. Taipei,China's manufacturers of electronics and information electronics products relocated the labor-intensive part of production to the PRC to take advantage of low labor costs and to explore its large market potential.

Of the investment in the electronics and information electronics industry to the PRC, 76 percent occurred after 1997, i.e., since the Asian financial crises. Rising competition in the information electronics product market led MNCs to ask their Taipei,China subcontractors to relocate their production facilities to the PRC to take advantage of the much lower wage rate there. In 2000, Taipei,China's investment in the electronics and information industry in the PRC reached US$1.5 billion, which accounted for 30 percent of the total investment of in the electronics and information industry to the PRC after 1991. The share of production undertaken overseas increased throughout the 1990s. Almost 60 percent of the total production was done outside of Taipei,China by 2000. Total production of information hardware in the PRC reached US$25.5 billion in 2000, which made the PRC the third largest information hardware producing country in the world, next to the US and Japan; while Taipei,China dropped to number four. The rapid and large amount of outward investment by Taipei,China's manufacturers also triggered serious concerns from the Taipei,China's government. Relocation of the labor-intensive stages to the PRC helped the electronics and information hardware industry expand its value added per worker further, overtaking all other manufacturing industries by 1998 (see Figure 4). Hence, by 2000, the electronics and information hardware industry had become the leading employer, exporter, value added, and labor productivity generator in Taipei,China's manufacturing.

[30] Of course, the ability to engage in the BTO operation can serve as an entry barrier for subcontractors to deter the entry of other competitors into the business.
[31] Therefore, the official record of Taipei,China's investment in the PRC started in 1991.

TABLE 8
APPROVED DIRECT INVESTMENT IN THE PRC, ELECTRONICS AND INFORMATION INDUSTRY (US$ MILLIONS)

YEAR	AMOUNT	CASES
1991	31,568	42
1992	34,555 (10%)*	31
1993	445,008 (1.19%)	1,190
1994	157,011 (-65%)	148
1995	214,796 (37%)	84
1996	276,862 (29%)	69
1997	875,044 (216%)	1,214
1998	758,975 (-13%)	300
1999	537,751 (-29.15%)	190
2000	1,464,775 (172%)	343
Total	4,796,345	3,611

* Figures in parentheses are the percent change compared with the previous year's figure.
Source: *Taipei,China Statistical Data Book* (Council for Economic Planning and Development 2001).

The early large foreign firm operations that offered the initial learning experience and the vertically decentralized local SME structure, facilitated by both market forces and trust relations, were instrumental in establishing the foundations of the electronics and information hardware industry in Taipei,China. Small firm efficiency and the economies of scope that offered considerable flexibility helped technological catch-up in Taipei,China's firms. However, the restructuring that followed the global recession in 1989-1992 pressured Taipei,China's firms to expand their scale to participate in large-scale OEM activities. Hence, the concentration ratio began to grow from 1997, which was enhanced by the outsourcing of labor-intensive activities to the PRC. The only Taipei,China OBM participant that was still left in the information hardware industry after 1992, Acer, became even larger to support its R&D operations.

IV. GOVERNMENT POLICY

As was shown in the preceding section, the dispersed industrial structure of Taipei,China where interfirm relations were established and sustained through market forces and trust helped SMEs achieve international competitiveness by integrating scale at the national level. However, it will be shown in this section that government policies were critical in establishing direction and stability for new firm creation and participation in high-tech activities. In addition to the usual support for basic infrastructure and education—primary, secondary, tertiary, and technical—the government targeted the growth of strategic industries, (including the electronics industry) and investment and coordination to facilitate learning and innovations. As Wade (1990) had argued, the government had control of the steering of the market. Not only that expansion in OEM assembly activities expanded firm size and productivity in the 1990s, the initial vertically decentralized and small firm industrial structure required government participation to engender the conditions for industrial upgrading and R&D activities.

The foundation of Taipei,China's industrial development was laid in the mid-1960s, when the government launched policies to stimulate industrialization; and then in the 1970s, when particular attention was directed to the development of high-technology industries. When the country encountered the first oil crisis in 1973-1975, the government realized that the economy was built on a fragile base of traditional and labor-intensive industries that were vulnerable to the fluctuations in the global market.

In the process of industrial development in general, the government intervened in markets by providing tax incentives and financial assistance to high-tech industries. Policy measures most relevant to the development of high-tech industries in general, and the electronics and information electronics industries in particular, included (i) the launching of Strategic-Industry Development Program in the 1980s and the follow-up enactment of the Statute for Upgrading Industry (SUI) in 1991; (ii) establishment of the Industrial Technology Research Institute (ITRI) in 1973; (iii) allocation of resources for industrial R&D particularly Science and Technology Projects (STP) Program in 1979; and (iv) establishment of the Hsinchu Science-Based Industrial Park (SIPA) in 1979.

A. Strategic-Industry Development Program and Statute of Industrial Upgrading

The Strategic-Industry Development Program, initiated under the Statute of Encouraging Investment (SEI) enacted in 1960, was the first statute that the government enacted to encourage private investment to stimulate industrial development in the sluggish economy after World War II. The SEI emphasized providing industry-specific incentives, such as 4–5 year tax holidays, accelerated depreciation, and tariff reductions and exemptions, to support the development of important productive industries, industrial and mining enterprises, and strategic industries. The SEI was designed to assist industrial development in general; development of high-tech industry started mainly after 1980 when the Strategic Industry Development Program was initiated.

In 1982, 152 products were selected as strategic products for development. By the end of 1987, the number increased to 214, almost half involving electronics and information technology products. The government introduced the Assistance Program for Strategic Industries in 1982,[32] which comprised a fund with NT$20 billion designated for lending to qualifying firms for the installation of machinery necessary for the production of strategic items. In addition, the loans had a preferential interest rate, which was 1.75 percent below the prime rate of the Bank of Communication. In 1991, the Strategic Industry Development Program was replaced by the Development Program of Ten New High-Tech Industry, which inherited the spirit of strategic industry development.

A survey of 1,407 firms in the shoe, leather, machinery and electronic machinery industries in Taipei,China conducted by Hou and San (1993, 395-6) showed that only 7.6 and 7.8 percent respectively of firms considered the offering of low-interest loans for R&D activities and providing tax credits for R&D expenditure as the most effective ways through which the government could assist the

[32] This particular financial assistance only applied to the strategic industries, not to other "important productive industries" or "industrial and mining enterprises" that were also covered by the SEI.

development of technology.[33] In other words, the majority of surveyed firms did not consider financial incentives from the government as effective in promoting technology advancement. Similar findings were noted by Lan, Wang, and Hwang (1992) and Sun (1987). Of the tax incentives used by enterprises, tax reduction or exemption were the most popular incentives to be applied, followed by tariff exemption, while accelerated depreciation was the least frequently applied by firms.

B. R&D Expenditure by Government and Private Sector

R&D generates information and knowledge; it is the driving force for technology advancement. Lichtenberg and Siegel (1989) had illustrated that R&D inputs were the determining factor in the growth of American productivity during the 1970s and 1980s. In the past two decades, R&D expenditure as a whole played an equally important role in Taipei,China's economic development. R&D expenditure increased from NT$1 billion in 1979 to NT$198 billion in 2000 (Table 9). In real terms, R&D expenditure increased 15 times over in the past two decades, with an average growth rate of 22 percent per year between 1979 and 1989, and 9 percent per year between 1990 and 2000, accounting for 0.83 and 2.02 percent of GNP in 1979 and 2000, respectively.

In 2000, close to 60 percent of the total R&D expenditure was devoted to technological development, 32 percent to applied research, with only 10.4 percent to basic research (Table 10). A similar pattern of allocation of R&D resources has remained throughout the past two decades. Clearly, Taipei,China's R&D devotion is heavily biased toward technology development and other applied technological matters, with less emphasis on basic research. Since basic research is the major source for the development of new technology and new products, the allocation pattern of R&D resources provides some insight into why Taipei,China is relatively strong in the development of manufacturing technology, and weak in product innovation.

Among all R&D expenditure, the share of government R&D increased from 53 percent in 1981 to 64 percent (highest) in 1985, then declined throughout the 1990s to 37.5 percent in 2000. The initial lead taken and subsequent direction and guidance offered by the government provided a catalytic effect to stimulate private investment in R&D activities, which gradually overtook government expenditure. Compared with other developed countries, in terms of full-time equivalent (FTE),[34] Taipei,China had 5.6 researchers per thousand labor force in 1998, which was lower than that in Japan (9.6 researchers) and the US (8.1 researchers); close to Germany (6 researchers) and France (6.1 researchers); and higher than Korea (4.3 researchers) and Holland (5 researchers) (*Indicators of Science and Technology* 2001).

One of the most direct indicators of the efficiency of R&D expenditures is the number of patents resulting from R&D activities. In 2001, Taipei,China's nationals (companies and individuals) as a whole

[33] The study found that 18.8 percent (the biggest percentage) of the surveyed firms considered educating more R&D people to be the most effective method to upgrade technology, followed by coordinating among firms to do joint research (18.6 percent), introducing new technology from abroad (17.2 percent), transferring technology through government-sponsored research institution (15.6 percent), and helping the firm establish their own brand names (8.8 percent).

[34] Since the figures of other countries are available in FTE.

TABLE 9
SCIENCE AND TECHNOLOGY INDICATOR (I)

YEAR	PERCENT OF GNP	R&D EXPENDITURE (NT MILLION)	S&T PROJECT FUNDING TOTAL (NT MILLION)	APPROVED US PATENTS (CASES)	
				ICT PATENT	PATENT
1979	0.83	9900	100		
1980	0.71	10562 (6.7%)	398 (298.0%)	—	—
1981	0.93	16414 (55.4%)	526 (32.2%)	80	12
1985	1.01	25397 (13.2%)	2794 (49.6%)	174	23
1990	1.66	71500 (30.5%)	6109 (32.8%)	732	166
1996	1.77	137955 (10.3%)	12424 (6.7%)	1,897	652
1997	1.86	156321 (13.3%)	12689 (2.1%)	2,057	812
1998	1.96	176455 (12.9%)	13699 (8.0%)	3,100	1,333
1999	2.03	190520 (8.0%)	14625 (6.8%)	3,693	1,659
2000	2.02	197631 (3.7%)	21853 (49.4%)	4,667	2,409
2001	—	—	—	5,371	2,803

Source: *Indicators of Science and Technology* (National Science Council 2001).

comprised the fourth largest patent holder in the US, next to US, Japan, and Germany (National Science Council 2001). The number of US patents owned by Taipei,China's nationals increased 66 times between 1981 and 2001, from 80 cases in 1981, to 732 cases in 1990; and to 5,371 cases in 2001 (Table 9). Among all the patents acquired, 15 percent (12 cases) were ICT-related in 1981, 23 percent (166 cases) in 1990, and more than half (52 percent or 2,803 cases) in 2001. The rapid increase of the US patents held by Taipei,China's nationals demonstrates the rapid development of the technological capability of Taipei,China's individuals and companies, particularly those in the electronics industry. The Pearson correlation coefficient between total R&D expenditure and the total approved US patents held by Taipei,China's nationals is as high as 0.95, which indicates a very strong linear association between the two variables. Even though the Pearson correlation coefficient does not imply any causality between variables, the very high coefficient implies that US patents held by Taipei,China's nationals are highly correlated with total R&D expenditure by Taipei,China's economy as a whole.

Table 10
Science and Technology Indicator (II)

YEAR	1981	1985	1990	1995	1996	1997	1998	1999	2000
R&D expenditure (US$ millions)	434 (100%)	637 (100%)	264 (100%)	4,585 (100%)	5,018 (100%)	4,789 (100%)	5,495 (100%)	5,744 (100%)	6,043 (100%)
Business firms (US$ millions)	250 (5758%	319 (50.09%)	156 (59%)	2,639 (57.6%)	2,903 (57.9%)	2,940 (61.4%)	3,458 (63.1%)	3,654 (63.3%)	3,789 (62.7%)
S&T research institute (US$millions)	123 (28.31%)	211 (33.09%)	73 (27.8%)	1,304 (28.4%)	1,477 (29.4%)	1,288 (26.9%)	1,376 (25.7%)	1,446 (25%)	1,529 (25.3%)
Universities & colleges (US$millions)	73 (16.73%)	107 (16.87%)	35 (13.2%)	642 (14%)	639 (12.7%)	562 (11.7%)	661 (11.1%)	673 (11.7%)	725 (12%)
Ratio of government to private R&D	53:47	64:36	46:54	44:56	42:58	40:60	38:62	38:62	37:63
R&D EXPENDITURE BY TYPE OF RESEARCH									
Basic research (US$ millions)	24 (6.7%)	92 (14.47%)	24 (9.1%)	561 (12.2%)	554 (11%)	482 (10%)	563 (10.2%)	610 (10.6%)	629 (10.4%)
Applied research (US$ millions)	210 (48.34%)	210 (33.%)	95 (36.0%)	1,317 (28.7%)	1,508 (30.1%)	1,453 (30.4%)	1,721 (31.3%)	1,825 (31.6%)	1934 (32%)
Technological development (US$ millions)	200 (44.9%)	335 (52.62%)	145 (59.04%)	2,707 (50%)	2,956 (59.o%)	2,854 (59.6%)	3,211 (58.4%)	3,339 (57.8%)	3481 (57.6%)
Total R&D manpower (persons)	19,604	45,104	75,233	105,822	116,853	129.165	129,305	136,323	137,622
Researchers	15,633 (79.70%)	24,600 (54.50%)	46,071 (61%)	66,478 (52%)	71,611 (61%)	76,588 (59%)	83,209 (64%)	88,708 (65%)	87,394 (63.5%)
Technicians	3,971 (20.30%)	12,110 (26.80%)	19,511 (25%)	25,635 (24%)	28,987 (24%)	34,021 (26%)	30,535 (23%)	31,674 (23%)	33,713 (24.5%)
Supporting personnel	— (18.70%)	8,394 (12%)	9,651 (12%)	13,709 (13%)	16,255 (14%)	18,556 (12%)	15,561 (11%)	15,941 (12%)	16,515
Researchers per 10,000 population	8.6	12.8	22.6	31.2	33.4	35.3	38	40.3	39.3
Researchers per 10,000 labor force	23.1	32.2	54.7	72.2	76.9	81.2	87.1	90.4	88.5

*The figure in parentheses represents percentage of the total amount.
Source: *Taipei,China Statistical Data Book* (Council for Economic Planning and Development 2001).

1. Science and Technology Infrastructure

Three major government-directed programs—Science and Technology Project program launched in 1979, Industrial Technology Research Institute established in 1974,[35] and Hsin-Chu Science-Based Industrial Park opened in 1980—played crucial roles in facilitating the development of the electronics and information technology industry in Taipei,China.

a. Science and Technology Project Program

The government was concerned over the reluctance of developed countries to transfer advanced technology and the difficulty Taipei,China's firms faced accessing technology from global markets in the 1970s. Poorly governed intellectual property rights and a weakly developed domestic absorptive capacity restricted international technology transfer. The government recognized that the small size structure of most industrial firms discouraged participation in risky and lumpy R&D activities. Hence, the Ministry of Economic Affairs (MOEA) launched the STP program to promote the development of domestic industrial technology. The MOEA entrusted government-sponsored S&T research institutes to carry out R&D, then transfer the results to the private sector. The government's long-term goal was to assist private firms upgrade and undertake R&D activities to strengthen their international competitiveness.

The STP program aimed to (i) develop new high-tech industries, (ii) upgrade the traditional industries, (ii) strengthen industrial infrastructure, (iv) enhance resource utilization efficiency, and (v) solve common industrial problems associated with pollution control and industrial safety (Wang and San 1999). The development of the STP program can be divided into four phases:

(i) *Phase One (1980-1985)*. Government funding started with NT$100 million (about US$2.8 million) in 1979, which was increased to NT$398 million in 1980 (Table 9). During this period, funding was increased by an average rate of 50 percent per year to NT$2,794 million in 1985. The STP accounted for around 11 percent of national R&D expenditure in 1985, which rose throughout the 1980s and 1990s.

Research topics were selected on the basis of industrial needs and compatibility with private companies' capabilities. ITRI gradually took control of the selection process, since the government entrusted it with 90 percent of total STP funding to carry out the research projects in 1980-1985, causing serious problems because of information asymmetry in the management of large-scale science and technology projects (Wang 1995).

The government produced several examples of government failures in the incipient period of the STP. Information asymmetry between research institutes and industry produced severe differences between projects undertaken in research institutes and technology

[35] Institute for Information Industry (III) is another government sponsored S&T research institute that was established in 1979 and related to the development of the information electronics industry in Taipei,China. However, III has a specific mission of introducing and developing software, assisting government agents and public enterprise in their computer projects, training and educating information professionals, and even providing market information to the private sector. Therefore, it is not included in this study.

that was market-worthy for industry. Researchers often proposed research topics based on their own technical interest, and had little knowledge of industry needs, which often resulted in ITRI developing technology that was technically sophisticated, but had limited commercial potential. Consequently, private companies were reluctant to absorb the research results due to the difficulty of commercializing them. Information asymmetry also existed between research institutes and the government. Since government officials had limited technical knowledge of the research topics proposed by research institutes, the government was forced to develop some tedious monitoring processes to avoid the criticism of crony favoritism. The implementation of R&D projects was sometimes delayed and thus reduced the interest of the private sector in participating in them.

(ii) *Phase Two (1986-1990)*. The total amount of STP program funding reached NT$6,109 million (US$225 million) by 1990, an 11-fold increase in real terms since 1980 (Table 9). This period was characterized by the first rapid expansion of the electronics and information industry. Firms accumulated technological capabilities from engaging in OEM activities with increasing demand for further advancement. The MOEA responded with an allocation of more than one third (36 percent) of STP program funding to support R&D projects on information electronics. Unlike the first phase, government failures were reduced in the second phase with better coordination between firms, research institutes, and government. The MOEA and research institutes incorporated the ideas and comments from the private sector into the development of research projects. In 1990, the MOEA began encouraging the private sector to participate directly in research projects and jointly with the research institutions.

(iii) *Phase Three (1991-1996)*. Taipei,China's electronics and information industry experienced its second rapid expansion, which was much larger in scale than the first wave. Taipei,China's manufacturers met challenge from competition by focusing more on technological advancement, which was strongly assisted by the STP program. The STP program increased the share of R&D funding to electronics and information technology industry to 40 percent. The total amount of funding made available for the electronics and information industry rose phenomenally as the STP program increased overall R&D project funding by an average of 18 percent per year.

The government improved the quality of investment in R&D activities by collaborating with private firms further in this period. The MOEA developed two new promotional schemes to facilitate this. The first required research institutes to invite private companies' participation in the research projects. Private companies became directly involved in the learning process and in steering the direction of the research projects as a result. The second required participating companies to contribute either research personnel or matching funds to avoid free rider problems.[36] The opportunity to participate in research projects was well received by private companies. By end of 1997, some 1,351 firms had participated in STP program projects (Hsu and Chiang 2001, 128).

[36] For example, companies could participate in the research projects by symbolically sending some junior staff and obtaining valuable research results.

(iv) *Phase Four (1997 to date)*. STP program funding was increased further to NT$21,853 million (about US$696 million) in 2000 (Table 9). Starting 1997, Taipei,China's electronics and information electronics companies had begun relocating production facilities to the PRC. As the leading electronics and information technology firms achieved sufficient technological upgrading, the MOEA decided to directly subsidize private R&D activities. Private companies were allowed to submit research proposals and compete with government-sponsored S&T research institutes for STP program funding from 1997. The direct participation of internationally competitive domestic firms alongside government-sponsored research institutes helped improve the STP program further. The MOEA allocated NT$1.5 billion (about US$48 million), which amounted to 7 percent of the total STP program funding,[37] to private companies. Private companies qualifying for STP program funding were required to pay matching funds ranging from 10 to 50 percent of total project costs, and were eligible to fully own the research results (Hsu and Chiang 2001, 126). Academics were included in the competition for STP program funding from 2000.

The MOEA also initiated the Industrial Technology and Information System in 1991 to entrust industry associations and research institutions to collect and analyze industrial information, such as on industry needs, market trend, new technology development, etc., to facilitate the selection of research topics and transfer developed technology to the private sector. In addition, the MOEA invited experts from industry, government, academe, and research institutes to discuss long-term planning and formulate industrial development policy on the basis of specific industrial targeting. Research institutes also appointed similar advisory committees. Each individual research laboratory in ITRI invites both domestic and foreign experts from industry, academe, and government[38] to provide them with information on domestic and international industry and technology trends.

2. Industrial Technology Research Institute (ITRI)

The Taipei,China government established a number of government-sponsored R&D institutes to stimulate innovative activities in the SME-centered industrial structure in the country. Among all the government-sponsored S&T research institutes, ITRI is the largest and most important. ITRI acted as the central pillar in the development of high-tech industries in Taipei,China, being the catalyst for new technology, new industry, and high-tech human capital development. With of 6,000 employees and 11 laboratories covering 11[39] technical areas, ITRI was able to achieve tremendous technological gains in 2001:

(i) Revenue of US$697 million, 52 percent of which came from the government to carry out STP program projects and provide a small amount of government subsidies, and 48 percent from the private sector to undertake contract research, joint development in the STP program, and technical services.

[37] The target is 10 percent of the total STP funding.
[38] The membership of the advisory committee sometimes overlapped with the ones invited by the MOEA.
[39] Comprising the areas of electronics, mechanical engineering, chemical engineering, energy and resources, aerospace, biotechnology, optical electronics, material, industry safety and hygiene, measurement, and testing.

(ii) Transferred 337 items of technology to 471 firms.

(iii) Filed 549 patents abroad and 313 patents in Taipei,China.

(iv) Hosted 1,148 training workshops (with 78,336 participants) and offered technical services to 30,427 firms in Taipei,China.[40]

a. New Technology Development

In the past 26 years, the STP program funding has been the major source of ITRI's research funding. The large-scale projects sponsored by the STP program usually are designed to develop technology that is advanced, essential, and sometimes generic. By implementing the STP program projects, ITRI led the steering of R&D for the development of domestic industrial technology, and contributed to the upgrading of overall industrial development.

The most famous case of development of new technology by ITRI was the development of the semiconductor technology through the sponsorship of the STP program (Mathews 1995, Chang and Hsu 1998). The Taipei,China government decided to develop the semiconductor industry in the early 1970s, considering it to be the industry that would sustain Taipei,China's economic development into the 21st century. The STP program allocated the funding and ITRI carried out the mission of planning and implementing the project. ITRI established the Electronics Industry Development Center, restructured later as the Electronics Research and Service Organization (ERSO), solely for undertaking semiconductor technology development. The center brought together a group of ardent and sophisticated young engineers who transferred the technology from RCA,[41] then assimilated the technology and improved it through in-house R&D until ITRI had full possession of the technology. ITRI and the STP program together planted the seeds for today's successful semiconductor industry in Taipei,China.

b. Creation of New Industries

Most new technology developed by ITRI is transferred to the private sector. However, if the technology has large commercial value, ITRI would spin off the technical team (usually also includes managerial, accounting, and marketing personnel) and create a private firm. Usually, ITRI would represent the government (since the project funding is from the STP program) and act as one of the investors in the company[42] and the original machinery and equipment used in the R&D would become part of ITRI's investment. ITRI does not get involved in the management of the company, and the company would have its own independent board of directors to appoint the top management. The government through ITRI would sell its stocks and invest the proceeds to support other STP program projects.

[40] This study focuses on ITRI's role in facilitating the development of information electronics industry in Taipei,China. ITRI's other contributions, like upgrading the traditional industry and improving pollution control in Taipei,China, is not be covered in this study.

[41] In the 1970s, RCA was a famous consumer electronics company in the US. It merged with the Westinghouse Company in the 1980s.

[42] The company has other investors from the private sector.

The development of the semiconductor technology comprised five projects, each targeted at developing one specific technology. By the end of the first project when ITRI had full possession of the technology that was transferred from RCA in the US, it relocated the R&D team to form the United Microelectronics Corporation (UMC) in 1979, which was the first semiconductor company in Taipei,China. ITRI subsequently spun off the 150 technical personnel involved in implementing the second project, i.e., involving very-large-scale-integration to form the Taipei,China Semiconductor Manufacturing Corporation (TSMC) in 1986.

TSMC as the first contracted IC-chip manufacturing company in the world (and an OEM manufacturer of IC chips), provided the demonstration effect to spur other firms into IC fabrication. Taipei,China now has 15 semiconductor manufacturing companies, making it the largest contracted IC-chip manufacturing country in the world. Taipei,China also had 56 and 180 IC design houses in 1990 and 2001, respectively. Prior to the establishment of TSMC, IC design could only exist in large vertically integrated companies, in which the IC design would be manufactured by the production department of the same company. Given the huge investment involved in the IC manufacturing facilities, without TSMC, no IC design houses could survive by themselves in Taipei,China.

When the IC design industry was growing, the demand for chip masking increased, which led ITRI to form the Taiwan Mask in 1990. By then, Taipei,China had a rough structure of a modern semiconductor industry. From the IC packaging operation started in 1975, the industry developed, comprising companies engaged in IC fabrication, design, and masking. The establishment of TSMC encouraged the entry of a large number of firms to offer chip design services, and subsequently induced the establishment of masking companies. This development process in Taipei,China's semiconductor industry has illustrated that government involvement was essential to create the external economies necessary for new technologies to realize their commercial potential (Ernst and O'Connor 1989).

In 1994, ITRI spun off another new company, Vanguard International Semiconductor Corporation to manufacture dynamic random access memory (DRAM) chips. ITRI had full possession of sub-micron[45] technology following the implementation of the third semiconductor project in 1990-1995. DRAM is a key component for manufacturing PCs and peripherals. Until the founding of Vanguard International, all needed DRAMs and SRAMs were supplied by Japanese and Korean semiconductor companies that sometimes were less cooperative in supplying DRAMs and SRAMs, since they also produced PCs and peripherals, and hence directly competed with Taipei,China's products in international markets.

Taipei,China's semiconductor industry comprised 315 firms in 2001(Figure 2), consisting of 180 design houses, 15 manufacturing companies, four mask companies, and 45 testing companies, with a production value of US$10 billion. The success of Taipei,China's semiconductor industry owes much to the "large" seeds planted by the STP program, which then was nurtured by ITRI through technology development, setting up of private companies, and strengthening of R&D capability in domestic firms.

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[43] One micron is a measurement that is about 1/80 of the diameter of a human hair. Sub-micro is a measurement that is smaller than one micro.

c. Spawning Ground for Technical Human Capital

Through the execution of projects initiated by the STP program, ITRI developed and cultivated the technological capability of technical personnel. When these technical personnel left ITRI to join private companies, they helped enhance the R&D capability of the private sector. Taipei,China's semiconductor industry had 80 percent of the top management—either directly or through spin-offs—originating from ITRI. ITRI's human capital spawning efforts was carefully charted through the following means:

(i) When ITRI spun off a whole technical team to form a private company, it retained the core technical personnel involved to ensure continuity in its development plans.

(ii) The establishment of new ventures provided both pecuniary and nonpecuniary incentives to make technical personnel willing to undertake technological development.

(iii) New ventures emphasized continuous interaction with markets so that development of the technology was compatible with the industry's needs.

(iv) New ventures served as a conduit to diffuse new technology from the STP program.

(v) New ventures served as a vehicle to assist industry, particularly traditional industry, to diversify their investment to high-tech industry (Hou and San 1993, 397).

ITRI's revenue generated from the private sector can be used as another indicator to assess its performance. These revenue trends can also show private sector participation rates in government-coordinated R&D programs in Taipei,China. According to ITRI's data, revenue from the private sector rose continuously from NT$336 million in 1980 to NT$1,000 million in 1990 and to NT$3,522 million (about US$991 million) in 2001, recording an average growth rate of about 14 percent per year from 1980 to 1990, and 17 percent per year from 1991 to 2001.

3. Hsin-Chu Science-based Industrial Park

Developing high-tech industries requires investors and a place with the requisite high-tech infrastructure to breed innovating firms. Taking Silicon Valley as a model, the Taipei,China government established the Hsin-Chu Science-Based Industrial Park in 1980, since it was adjacent to National Chiao Tung University (NCTU), National Tsing Hua University (NTHU), and ITRI, where firms and institutions could be clustered.

SIPA was created to stimulate high-tech investment. Aiming to produce an environment suitable for S&T research, SIPA provided enterprises set up in SIPA with inexpensive but sufficient industrial infrastructure (e.g., land, building, water, and energy), comfortable living facilities, tax incentives, and financial subsidies for R&D projects. The firms eligible to set up in SIPA had to fall into six targeted categories, namely, integrated circuits, computer and peripherals, telecommunications, opto-electronics, precision machinery, and biotechnology.

From 19 in 1980, the number of high-tech companies operating in SIPA reached 312 in 2001. Apart from 19 biotechnology companies, the remaining 293 firms were in electronics-related industries.[44] In 2001, SIPA as a whole had capital investment of US$25.5 billion (compared to US$50 million in 1980); close to 100,000 employees (1,126 employees in 1983); and sales of US$19 billion (US$75 million in 1980). In 2000, firms in SIPA spent 5.4 percent of their total annual sales on R&D, which was more than four times higher than the 1.3 percent of the overall manufacturing industry. IC companies in SIPA as a whole contributed the majority (71.2 percent) of total R&D expenditure incurred at SIPA, which helped SIPA file 2,376 patents (2,047 were IC-related) in Taipei,China and another 1,265 patents (1,076 were IC-related) from abroad. SIPA alone accounted for about half of the patents held by Taipei,China's nationals in the United States.

The interaction between ITRI, SIPA, NCTU, and NTHU is an important part of Taipei,China's industrial infrastructure. ITRI set up the incubators in the incipient stage, while SIPA helped fertilize and nurture the technology developed by ITRI by providing the institutional facilities and networks to reduce the risks and uncertainty associated with lumpy R&D investment.

Companies in SIPA initially recruited experienced talent, with ITRI being the prime source for middle-level talent, and NCTU and NTHU the main source for entry-level talents (Chang and Hsu 2001, 289). Usually new graduates joined ITRI to gain experience before switching to companies in SIPA. However, too frequently experienced technical personnel joined companies in SIPA, and some key projects initiated by the STP program suffered from shortage of experienced technical personnel (Chiang and Hsu 2001, 287). Nevertheless, as the companies in SIPA matured, the increased supply of technical personnel enabled them to conduct their own R&D, hire new graduates, and provide in-house training, which allowed ITRI to focus on advanced research and frontier technology.

SIPA made two major contributions to the development of high-tech industries in Taipei,China. First, companies in SIPA attracted a large number of talents from abroad, especially overseas Chinese, which helped reverse the brain drain that took place in the 1960s and 1970s.[45] These returning expats played an important role in upgrading the technological level of companies in SIPA. San (2001), in 1999, surveyed 84 companies in SIPA and discovered that the largest contribution of overseas recruits was bringing back technology and knowledge of new product development,[46] which was critical in guiding local engineers and technicians to conduct R&D activities, and to strengthen technology transfer negotiation capabilities of local firms against foreign companies. Second, SIPA helped strengthen the "invisible" environment to stimulate systemic synergies by forging strong network cohesion within the industrial park (Mai, Cheng, and Hsu, 1999; San 2001).

[44] Of these firms, 123 were in the semiconductor industry, 51 in the personal computer industry, 57 in the telecommunications industry, and 51 in the optoelectronics industry.

[45] By the end of 1998, there were 3,056 scholars and experts from abroad available to take position in SIPA firms, who thereafter established 109 (out of 312) enterprises in SIPA in 2000.

[46] Followed by assisting product sales and general management.

V. CONCLUSION

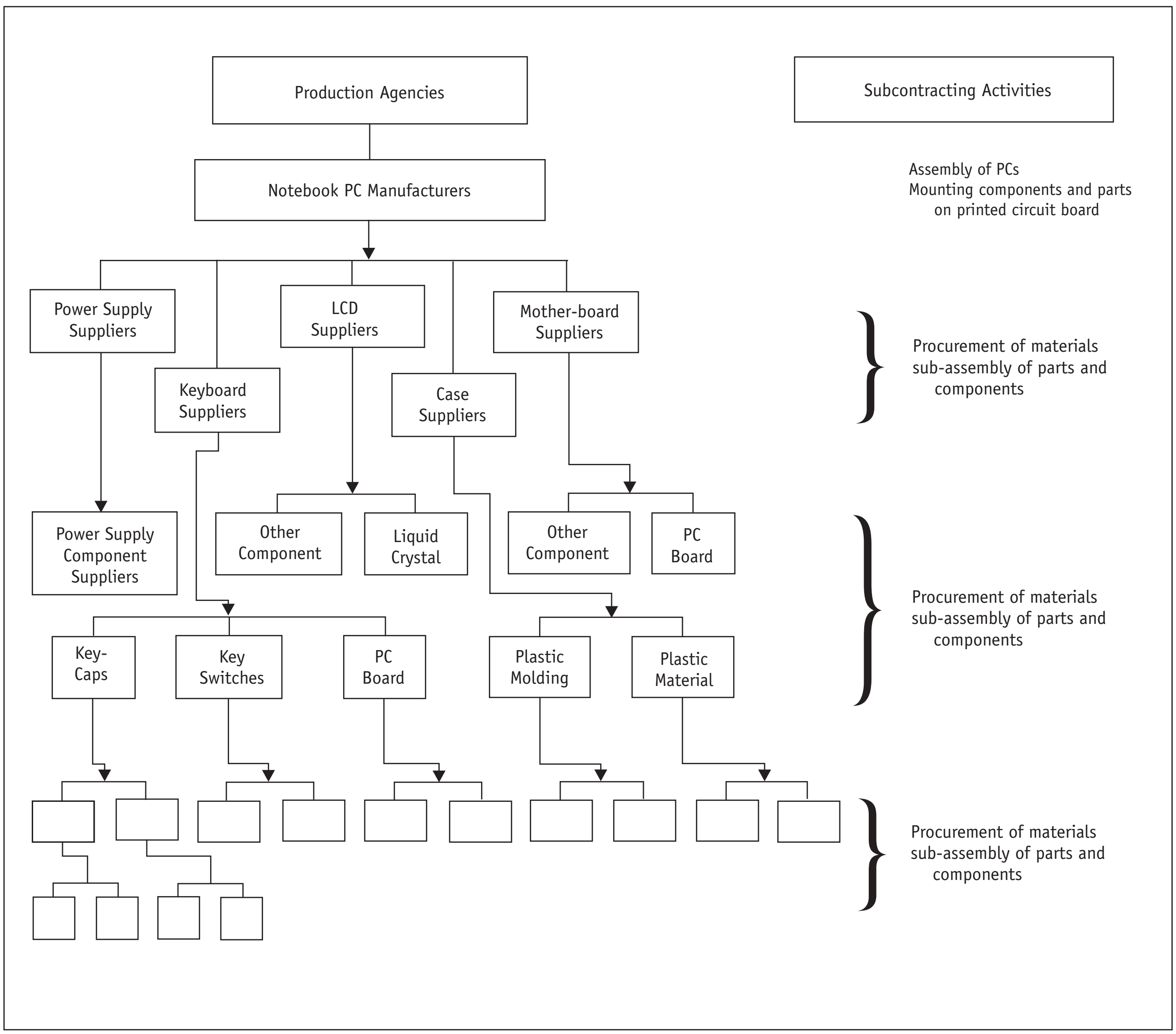
This paper presented the remarkable success of the development of the electronics and information technology industry in Taipei,China. From being heavily dependent on foreign technology in the 1960 and 1970s, Taipei,China's firms successfully negotiated the daunting currents of competition to participate in new product development by the 1990s. Taipei,China's initial small-firm structural endowments were effectively harnessed by the firms—through the interaction of markets and trust—that allowed small firms to integrate demand to achieve scale economies at the industry level and to quicken learning. The changing nature of global manufacturing in the electronics industry especially computers favored small firm flexibility and hence stimulated rapid entry and exit of SMEs in the 1980s. However, as the demand for quality became more stringent, the shakeout that followed favored large-scale OEM manufacturers. In addition, the increasing shift toward horizontal integration attracted contract manufacturers equipped with R&D capabilities. Taipei,China's firms with designing and R&D capabilities—including OBM operations of Acer—became increasingly large, which consequently raised the concentration ratio in the electronics and information technology industry in the 1990s.

Taipei,China's firms operated in an overall low-distortion environment in the market place that was untamed by government control. Export producers in the electronics and information industry faced hardly any import controls in Taipei,China. SMEs offered ample supply of entrepreneurship in Taipei,China. Through Taipei,China's unique vertically disintegrated industrial structure, SMEs are able to engage in OEM exports. Exposure to international competition helped improve their production efficiency. In addition, the vertically disintegrated industrial structure best suited the manufacturing of electronics and information electronics components as the production process could be divided into smaller tasks. Individual firms in the system specialize in one production task based on their core competence, and open competition motivated private firms to upgrade their technological capability.

However, two constraints restricted further expansion involving the vertically decentralized structure of SMEs in Taipei,China by the late 1980s. First, the increasing demand for quality and reliability shifted contract manufacturing to larger OEM producers who were able to upgrade and undertake horizontal integration. Second, rising production costs and the emergence of low-cost sites forced Taipei,China's firms to participate in higher value-added activities that included new product development. Hence, government intervention shifted from merely facilitating roles—using incentives and grants—to more pervasive roles that included launching of the STP program to promote R&D, founding of ITRI that became the foundation for new technology development, creation of new firms and human capital involved in high technology, and establishment of SIPA, which helped strengthen network cohesion and stimulate systemic synergies from the clustering of high technology infrastructure, institutions, and firms. Coming in the wake of the global recession of the mid-1980s, the government pursued these initiatives aggressively. The initial government failures were tightly appraised with strong private sector participation so that government's R&D initiatives were smoothly intermediated to meet industry needs.

The government also adopted industrial policies that were complementary to the SME-centered economic structure. To overcome the problems of scale economies and investment lumpiness associated with R&D activities, government established the STP program and government-sponsored S&T research institutes to, inter alia, support SME operations. The SIPA fostered an environment conducive to investment in high-tech industry, and provided a spawning ground to nurture the technology sponsored and developed by the STP program and ITRI. Government support was obviously central to the initiation, direction, and eventual upgrading of technology in the electronics and information technology industry, including the creation—through ITRI—of the first independent IC fabrication and manufacturing firm in the world, TSMC. Therefore, the Taipei,China's government essentially "made", rather than "picked", several of the winners, which is consistent with Wade's (1990, 334) argument.

APPENDIX: NOTEBOOK PC MANUFACTURE AS AN EXAMPLE OF HOW THE SUBCONTRACTING-BASED PRODUCTION SYSTEM WORKS IN TAIPEI,CHINA



A notebook PC manufacture, for example, receives a large order from a foreign buyer[48] (Diagram 2). First, the PC manufacturer would purchase all components and parts, such as liquid crystal display, case, printed circuit board, keyboard, power supply, and other components from independent vendors in Taipei,China (Levy & Kuo 1991), then, subcontract out the work of mounting components and parts on printed circuit board to other plants, due to its own limited production capacity. Once all parts and motherboards (bare printed circuit board with complete inserted components and parts) are delivered by vendors and subcontractors, the notebook PC manufacturer would start the final assembly of the notebook PCs. Usually, the notebook PC manufacturer would also subcontract out a portion of the final assembly of the notebook PC to other PC manufactures, if the quantity required by the order has exceeded its own capacity. First-layer parts and component suppliers such as keyboard, case, and motherboard suppliers would also purchase the needed parts and components from independent vendors in Taipei,China, and subcontract out some or all of the sub-assembly of parts, like motherboard assembly,[49] to the motherboard supplier if it is needed. Once the first-layer suppliers acquire the needed parts and components, they would start their parts assembly. Meanwhile, the second-layer suppliers, such as suppliers of keycaps and keyswitches for keyboard manufacturing, plastic material and plastic molding for case manufacturing, and bare printed circuit board and related components for motherboard assembly etc., would rely on similar subcontracting activities to acquire the needed components and parts to facilitate their final assembly work. Therefore, subcontracting is a top-down, network-based production system.

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[47] In the early days, especially in traditional industry, the foreign orders usually were acquired by trading companies. Then, the trading companies would subcontract their orders to different manufacturers. Hsing (1999) has a good explanation on the role played by trading companies in the fashion shoe industry, and in general the traditional industry.

[48] Motherboards are an essential part in manufacturing all electronics products and their individual parts.

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