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Abstract

A decade of stagnation and financial crisis have discredited the heavy-handed industrial policies of Japan and Korea, particularly preferential allocation of capital to large companies. In contrast, the remarkable growth of specialized yet flexible computer and semiconductor firms in Taiwan has been supported by a very different type of industrial policy. Taiwan's "ITRI model" combines development initiative and engineering support from the quasi-governmental Industrial Technology Research Institute with commercialization by a mass of small to medium-sized firms in the adjacent Hsinchu Science-Based Industrial Park. The government provides technological support for both long-term development and specific innovative products, but it has exercised extreme restraint in the allocation of capital and sponsored the development of a thriving venture capital industry.

Some industries, however, have proved resistant to the ITRI model. A prime example is hard disk drives. Hard disks combine high barriers to entry and brutally short product cycles. Moreover, they lack the stable architecture underlying notebook computers or monitors. Even with help from ITRI, Taiwan's small firms proved unable to keep up with the rapid development and growing economies of scale in hard disks. However, when they failed at disk drives, they proved capable, with additional assistance from ITRI, of moving quickly to related products with much lower barriers to entry, such as CD-ROMs and CD-R disks and drives.

Notwithstanding the limitations revealed by the hard disk case, Taiwan's ITRI model is likely to attract increasing attention from developing countries that recognize the dangers of the Korean approach, yet hope to improve their standing in the international division of labor.

As a decade of economic and technological stagnation in Japan and the financial crisis in Korea cast increasing doubt on the model of close cooperation—and collusion—between government and big business, attention swung toward Taiwan, an island noted for its economic flexibility and technological dynamism. In the 1990s Taiwan emerged as an extraordinarily successful producer of computers and semiconductors. Firms based in Taiwan led the world in production of notebook computers, motherboards for desktop computers, monitors, mice, scanners and other computer-related products.¹ Taiwan's specialized semiconductor manufacturers, once far behind the giant Korean *chaebol* conglomerates, engaged in massive investments that seemed likely to propel them past the Koreans to third place behind America and Japan in the first few years of the new millennium. They even purchased American producers of central processing units to challenge Intel.²

In this panoply of computer successes, a single major product stood out as a glaring failure: hard disk drives. Although Taiwan was one of the world's largest consumers of hard disks, it was never a major manufacturer of drives and by the late 1990s produced virtually none.³ This failure stands in puzzling contrast to the great success of Singapore in hard disks. With one-seventh Taiwan's population and a small fraction the number of engineers and computer entrepreneurs, Singapore emerged as the world's largest producer of hard drives. The drives, in turn, contributed a significant share of Singapore's gross national product.⁴ Taiwan's distance from Singapore lengthened development time and decreased flexibility of design for local computer producers, particularly small firms.⁵

Hard disk production in Taiwan did not founder for a lack of effort. On the contrary, government and industry recognized the significance of hard disks both in

their own right and as a component in computers. Foreign investors built several hard disk factories in Taiwan. Local firms also strove to break into the disk market. The government provided research and development (R&D) support, organized a consortium and strategic alliances and supported the efforts of specific private firms. When they faltered, the government designated hard disks as a critical industry and formulated numerous plans to reorganize and resurrect the industry. Nevertheless, almost all of the government's initiatives failed. Local firms dropped production of hard disks and moved on to alternative products, notably variations on the CD format, such as CD-ROMs (read-only memories) and CD-R (recordable CDs).

This record presents an obvious puzzle: why was Taiwan unsuccessful in hard disks when it did so well in most other computer products? Less obvious but equally puzzling: having invested so much effort in promoting hard disks, why were the government and firms in Taiwan willing and able to cut their losses and move on to other products? The answer to both puzzles lies in the dynamics of the "ITRI model," Taiwan's combination of development initiative and engineering support from the quasi-governmental Industrial Technology Research Institute with commercialization by a mass of small to medium-sized high tech startup firms in the adjacent Hsinchu Science-Based Industrial Park. By reducing the barriers to entry in high-tech production, ITRI encouraged the development of an industrial district based on small firms. The small startups proved extraordinarily entrepreneurial, flexible and efficient. In products such as motherboards or scanners, their quick response and low cost of production placed unremitting pressure on competitors from other countries. However, the challenges presented by hard disk drives proved resistant to the strengths of the ITRI model. Hard disks combined high barriers to entry and brutally short product cycles. Moreover, they lacked the kind of stable underlying

architecture provided for desktop or notebook computers (much less monitors or scanners) by Microsoft software and Intel-compatible microprocessors. Even with help from ITRI, Taiwan's small and medium-sized firms proved unable to keep up with the pace of developments and the growing economies of scale in hard disks. However, when they failed at disk drives, they proved capable, with more help from ITRI, of moving quickly to optical recording products such as CD-ROMs and CD-R disks and drives, products with much lower barriers to entry.

THE ITRI APPROACH TO SECONDARY IMPORT SUBSTITUTION

The ITRI model developed in the 1980s as an attempt to take an active role in developing high technology industries without resorting to the extreme statist approaches adopted in some neighboring countries. In Japan, the government actively utilized tax, tariff and financial instruments to encourage private firms to explore new products, develop economies of scale and scope and accelerate movement along industrial learning curves.⁶ Neo-classical economists, though skeptical of most industrial policy, came to acknowledge that in principle coordination of investment and strategic trade practices could confer significant advantages on domestic firms.⁷ Similarly, Amsden and Woo showed that in late industrializers such as Korea, aggressive utilization of preferential lending by the government led to extremely high and sustained investment rates that propelled rapid growth and technological learning.⁸ In contrast, Bernard and Ravenhill demonstrated, through the early 1990s the absence of pilot agencies capable of promoting secondary import substitution left most Southeast Asian countries far behind Japan and Korea in high tech industries. Nor was there any clear evidence that these trailing geese (with the partial exception of tiny Singapore) would ever catch up with Japan, the lead goose, for they depended

on Japan in a way that Japan had never depended on other countries in its early development.⁹ Even Hong Kong, whose growth record matched that of Korea, failed to develop a high tech sector.

Despite the manifest ability of Japanese and Korean firms to move into high tech industries, most observers remained skeptical of arguments justifying infant industry and secondary import substitution policies. The attempt to achieve economies of scale often results in inefficient factories utilizing only a small share of their capacity. Efforts to promote upstream industries such as auto parts often throttle the development of downstream industries such as auto assemblers. The opportunity cost of attempting to accelerate acquisition of comparative advantage in heavy and high-tech industries is often the starving of agriculture and light industry, which offer quicker and surer opportunities to increase productivity, and provide employment opportunities to the whole population. Infant industries often fail to grow up, requiring indefinite protection or subsidy. Perhaps worst of all, political and bureaucratic systems tend to become captured by the failed objects of promotion. The government not only fails to target new opportunities but also becomes chained to old failures.¹⁰ Even when aggressive government support of import-substituting industrialization is initially successful in stimulating investment and growth, it may lead to macroeconomic imbalances and excessive investments that fail to earn adequate returns and overwhelm the banking system with unrecoverable loans. The Asian financial crisis that broke out in 1997 provided a vivid illustration.

Policymakers in Taiwan were receptive to these warnings about excessive controls on capital allocation and foreign investment. Even in the 1960s and 1970s, when the government was quite willing to use protection, promotion and state-owned enterprises to target new industries, it was much more restrained in the allocation of

bank capital to large private corporations than were governments in Korea or Japan.¹¹ Starting about 1980 the government decisively moved away from promotion of heavy industry and toward high tech.¹² Protection declined in importance and Taiwan remained more open to direct foreign investment than did Korea or Japan (though much less open than the entrepot city-states, Hong Kong and Singapore). Instead of capital and protection the government provided technological assistance. The government's main promotional tool was the Industrial Technology Research Institute (ITRI), located about an hour south of Taipei in Hsinchu (Xinzhu), home of two of Taiwan's leading technological universities, Qinghua and Jiaotong. From its founding in 1973, ITRI specialized in reverse engineering of the latest foreign products, technology transfer to local firms, organization of research and development consortia and provision of engineering services. The Institute collated and translated reams of information on the latest trends in technology and markets and represented Taiwan in international negotiations on product standards and intellectual property rights. Manufacturing of final products it left strictly to the private sector. In a few cases, particularly in semiconductors, ITRI privatized its pilot laboratories when their activities verged on mass production. In the early 1990s, when Taiwan tried to promote the production of hard disks, ITRI's staff exceeded 6,000, of whom over 500 held PhDs and 2100 had masters degrees; by 1998 over 800 held PhDs. ITRI combined both stability and dynamism, with personnel turnover of about 15% per year, most of it to private firms in nearby Hsinchu. About one-third of ITRI's income derived from services provided to private firms. The Ministry of Economic Affairs and other government agencies subsidized the rest in the form of support for various special technology projects. In 1992, at the peak of ITRI's interest in hard disks, the

Institute mobilized nearly seventy researchers to work on various aspects of hard disk technology, as many as all the assembly companies combined.¹³

Next door to ITRI, the National Science Council, a Cabinet-level agency, established the Hsinchu Science-Based Industrial Park to house high-tech companies. The Park provided standard factory accommodations and superior infrastructure such as telecommunications links and expedited customs service. Investors in the Park received generous tax breaks. To entice scientists and engineers back from North America, the government established in Hsinchu the only public schools in Taiwan providing English-language instruction. With encouragement from the government, venture capital firms and legal services such as consulting on intellectual property rights emerged as another crucial regional asset. The government occasionally provided subsidies or low-cost loans for production of specific new technologies, but it established strict screening procedures, limited the amounts and most important rarely invested directly in specific firms or requested state-controlled banks to provide loans to particular firms.

The synergy provided by ITRI, the two universities, the science park and government incentives quickly bore fruit. Barriers to entry by new startups in computers and semiconductors fell to modest levels. Production and exports soared. Within a decade the ITRI-university-Park complex formed an agglomeration of entrepreneurship and skilled manpower that became increasingly independent of the government incentives that had initially drawn firms to Hsinchu.¹⁴ Hsinchu earned acclaim as the second Silicon Valley. By the mid-1990s, firms from Taiwan constituted the third-largest source of products in the information industry, trailing only the U.S. and Japan and pulling away from Korea.¹⁵ Taiwan's computer and

semiconductor industries barely noticed the financial crisis that devastated Korea and much of the rest of Asia.

And yet Taiwan failed in hard disk drives. The high capital costs and rapid technological change endemic to the disk industry created high barriers to entry. To overcome them the government would have had to do one of three things. It could have ordered a state-owned enterprise, or ITRI itself, to enter volume manufacturing. Or it could have provided major financial incentives to encourage the development of a private “national champion” firm. Or it could have lavished huge subsidies on foreign investors along the lines pioneered by Singapore. Unwilling to embark on any of radical departures, the government rejected entreaties from the industry and watched hard disk production wither—and immediately turned its attention to products that could be produced within the ITRI model, such as CD-ROMs.

THE DEVELOPMENT OF THE HARD DISK DRIVE INDUSTRY IN ASIA

Hard disk drives are classic “mechatronic” devices combining software, electronic components, exotic materials and fine machinery. Magnetic heads read and write data to one or more rapidly spinning coated metal platters. A spindle motor rotates the platters while a stepper motor or voice coil motor positions the recording head. The heads fly at enormous speeds just over the surface of the platters; if they crash, they wipe out sections of the user’s data. Extraordinarily fine tolerances and levels of quality control are thus essential.

IBM invented the hard disk drive in 1956 and introduced the first sealed drive in 1973. Improvements in technology enabled manufacturers to decrease the size and price of the units. In 1980 Seagate introduced 5.25” units suitable for use in personal computers. They provided much greater storage capacity than floppy disk drives, but

cost significantly more. Desktop computers typically utilized 5.25 or 3.5 inch drives, while the units in notebooks were typically 2.5” or even smaller. Technological improvements continually increased storage capacity and decreased prices. By the end of the decade hard disks had become standard components of PCs and notebooks, accounting for nearly 30% of total cost.¹⁶

As prices of disk drives plummeted, American manufacturers looked overseas to cut production costs. Some basic assembly operations migrated to Thailand, Malaysia, the Philippines or even China. The bulk of production, however, concentrated in Singapore. The island state featured an efficient transportation and communications infrastructure, an accommodating and honest bureaucracy, and generous tax incentives for foreign investors. Wages, while significantly higher than in Thailand or Malaysia, remained far below those of the United States. As early as the 1970s electronics firms produced floppy disk drives in Singapore. Beginning in 1983 production expanded to include hard disks. Over the course of the 1980s virtually all of the American hard disk firms moved mass production facilities to Singapore, including Seagate, Miniscribe, Maxtor, and Micropolis. Japanese firms, in contrast, paid a high price for excessive confidence in the superiority of their engineering, quality control and automation. They did not invest in Singapore in the 1980s and remained minor players in an industry that seemed ideally suited to their strengths in integrating electronics and fine machinery (though they did export many parts to Singapore).

The concentration of foreign assemblers encouraged the development of a broad base in basic parts, repairs and infrastructure. By the end of the 1980s Singapore had established formidable economies of scale and scope. Though virtually none of the drives or the most sophisticated parts was designed in Singapore,

the island produced about half of the world's hard disk drives. Drives, in turn, became the single most important product in Singapore's economy.¹⁷

HARD DISK DRIVE PRODUCERS IN TAIWAN

The hard disk drive industry developed slightly later in Taiwan and attracted only one (briefly) successful foreign investor.¹⁸ In the early 1980s a number of local companies rushed into the production of floppy disks, particularly for small, non-IBM compatibles such as Atari. Tatung (Datong) and other traditional local electronics firms briefly tried to serve as contract assemblers for American hard disk companies, but they were unable to keep up with the rapid product cycles and brutal price competition.¹⁹ In 1983 Kuimao, a local offshoot of the American firm Qume founded in the Hsinchu Science-Based Electronics Park by returnees from Silicon Valley, began with floppy-disk drives and licensed designs for hard disks. After initial success with floppy disks, the loss of a major order from IBM cut the company's revenues by 80%. Qume exited the floppy disk industry, shifting its energies to production of printers without ever shipping hard disks.

Many of the American disk manufacturers that eventually settled in Singapore also considered investing in Taiwan. However, with minor exceptions noted below, they ended up bypassing the island. Through the 1980s, as Singapore was establishing its dominant position as a producer of drives, demand for hard disks in Taiwan remained limited. At the time Taiwan specialized in low-end "clone" computers and as of 1986 only 12% of them carried hard disks as standard equipment. Crossover did not occur until 1989-1990, when the proportion of Taiwan's then much more substantial production carrying hard drives suddenly shot up from 40% to 85%.²⁰ Nor did the government aggressively attract foreign producers. The

technocracy was preoccupied with semiconductors, the production of which began in the mid-1970s and only took off in the mid-1980s. The government also had doubts about the benefits to Taiwan of encouraging local production by foreign hard drive manufacturers. As the head of ITRI's Opto-electronics Institute put it, "We can't go back to just assembling products."²¹ Taiwan remained unwilling and unable to match Singapore as a host for direct foreign investment. It lacked Singapore's efficient, virtually incorruptible bureaucracy, supremely efficient infrastructure and virtually universal competency in English. Unlike Singapore, Taiwan contained a substantial indigenous entrepreneurial class and significant technological skills. If it had tried to match the financial and tax incentives Singapore offered foreign investors it would have imposed a major competitive disadvantage on its own producers. Tiny Singapore could afford to rely on a small number of multinational corporations; Taiwan could not. Finally, Taiwan was much more reluctant to provide open access for foreign skilled and white-collar labor. It welcomed the return of scientists and engineers of Chinese extraction (*haiwai Huaren*, usually from Taiwan itself, occasionally from Hong Kong, Southeast Asia or, rarely, mainland China), but the government made it extremely difficult for firms to bring in non-Chinese foreign experts. In fields such as electrical engineering and chemistry this was not a major problem, since many returnees possessed the necessary skills. However, in fine machinery and many specialized sub-specialties, as well as in headquarters positions in which a high degree of competence in English was required, restrictions on labor inputs placed Taiwan at a serious disadvantage relative to Singapore.

Later, in the mid-1990s, Taiwan did undertake a drive to entice foreign multinational corporations to go beyond manufacturing and establish regional operating centers in Taiwan, but the effort yielded only meager results. The vast

majority of Western corporations and all Japanese companies established their East Asian headquarters in Hong Kong or Singapore.²² If Taiwan had tried to compete with Singapore in hard disk drives in the 1980s, it would have gained only labor-intensive assembly operations at which it had no great comparative advantage and which would have done little to upgrade its skills.

Unable to attract foreign companies to establish high-end operations in Taiwan, the government tried to develop indigenous capabilities. The main instrument was ITRI. Within ITRI, the Electronics Research and Services Organization (ERSO or *dianzisuuo*) took initial responsibility for research into magnetic recording heads, metal platters and other key technologies for hard disk drives. In 1984-85 ERSO organized a research and development consortium to produce hard disk drives.²³ The Industrial Development Bureau of the Ministry of Economic Affairs, Taiwan's "pilot agency" for industrial policy, provided a subsidy of about USD \$500,000. The five members included several of Taiwan's leading electronics companies (Tatung, Jinbao, Shengbao, Yuandong Electric and Vidar Sun Moon Star [Sanguang Weida]) but none of its emerging computer specialists. The private companies paid fees and received assistance in technology transfer while ITRI conducted the large bulk of research in house. The "consortium" was thus an example of partitioned and subsidized technology transfer rather than truly cooperative development. Keeping up with fast-moving hard disk technology proved to be a formidable challenge. By the time ITRI completed prototypes of five and ten-megabyte drives they were obsolete. The hard disk project was one of ITRI's first consortia. As with early efforts in other areas, ITRI found it difficult to bring products to market in time for the clients to earn a profit. None of the five firms brought significant skills to the project. Tatung began small-lot production of the

ITRI-derived designs and won a few foreign orders but soon dropped plans for mass production. In other high tech fields such as notebooks computers, work stations and personal digital assistants, follow-up consortia were considerably more successful than their predecessors, but ITRI did not organize new consortia for hard disks.²⁴

In the half-decade following the failure of the ITRI consortium, six significant producers emerged. Returnees from the U.S. established two, while three others were founded by locals and depended in varying degrees upon ITRI for technology. Only one was a “pure” foreign investor without preexisting ties to Taiwan. First to arrive was Cogito (Gaozhi), a Silicon Valley startup company established in 1982 by engineers from Taiwan with a USD \$25 million dollar investment from Qingfeng (sometimes written Chinfon), a large conglomerate in Taiwan best known for assembling Hondas and manufacturing Sanyang motorcycles. In 1985, just as the ITRI consortium got under way, Cogito established an assembly operation in Taiwan. Cogito never succeeded in reaching economies of scale and closed its Taiwan operations a few years later.²⁵

Priam Systems, a Silicon Valley startup firm, established a production subsidiary in Hsinchu at the end of 1986. Priam settled on Taiwan more for its high level of production engineering than its rapidly expanding but still limited market for hard disks. After graduating from nearby Jiaotong University, the President of Taiwan Priam, Liu Wenwei, had worked at both Hewlett-Packard and former floppy disk maker Qume. He bought some of the plant and production equipment left behind by Qume. Priam Systems moved to Taiwan a production line for low-end 5 1/4” by 1 1/2” 30-85MB drives. The mother company provided all designs and sent engineers from the U.S. to handle all production problems. Taiwan Priam shipped virtually all output back to the mother company. According to local officials, yield rates that had lagged

at 65% in the U.S. reached 77% in Taiwan. The company produced about 20,000 units its first year (though fewer than 500 found domestic buyers) and developed plans to install a second production line for 5 1/2" by 1" 380MB drives. Unfortunately for Taiwan Priam, the mother company fell into difficulties and by 1990 the subsidiary shut down the production lines.²⁶

Microscience International, another Silicon Valley startup, achieved somewhat more success. Founded, like Cogito, by "overseas Chinese" from Taiwan, Microscience commenced operations in the U.S. in 1982 and built a plant in Singapore in 1985. It opened a larger and more sophisticated plant in Taiwan in 1987, after which it began closing its American production lines. The initial technology for its 5.25" drives came from Germany's Siemens. Acer, Taiwan's largest computer manufacturer, and Formosa Plastics, then Taiwan's leading industrial group, led the investors in the local subsidiary Taiwan Microscience (Taiwan Weike). For a time Taiwan Microscience established itself as the largest hard drive manufacturer on the island. In the first year of production the company sold over 100,000 of its half-height 5.25" 40 MB drives and still could not meet demand. At its peak the company employed about 320 staff. The company shipped all of its output back to the mother company. Despite the explosive growth of computer output in Taiwan, Microscience never succeeded in selling to local firms. In 1990 Microscience moved into larger quarters and hired more staff in anticipation of joining the global shift to 3.5" drives, but Microscience International was unable to complete designs on time. It lost most of its design staff and fell into financial distress. The Taiwan subsidiary tried to rescue the mother company by acquiring 95% of its stock, in the process incurring huge debts. After a futile effort to reenter the market with 3.5" drives acquired from Siemens led only to bulging inventories,

Microscience shuttered its doors in January 1992. At the end of the year company reorganized itself as Quanzhen Keji and applied to reenter the Science-Based Industrial Park using technology from Siemens (itself soon to exit the brutal competition of the hard disk business), but it was never able to reestablish mass production. Creditor banks obtained a court order and sold Microscience's plant and equipment at auction.²⁷

In 1989, as growth in Taiwan's computer production continued to expand and an increasing proportion of computers carried hard disk drives as standard equipment, three local firms broke into the hard disk industry. All three depended upon modest investments by smallish conglomerates that wanted to maximize profits rather than bank loans or market share. Two of the three relied upon designs from ITRI. None ever accounted for a large proportion of Taiwan's total output, but one firm made a serious effort to develop independent design skills and with help from the government managed to stay in business nearly a decade.

Magtron (Yongjin) led the way in early 1989 with an investment from Zhengfeng Chemicals, a local chemical company. Magtron established a plant not in the science-based industrial park but in Yangmei, an industrial zone not favored with incentives for high tech production. The company bought an aging design for 5.25 inch, half-height 170 MB drives from the failing American maker Century Data Systems for just USD \$250,000. The cheap design turned out to be an expensive mistake. Purchasers returned many of the 8,000 Central Data drives that Magtron produced. Magtron signed a technical cooperation agreement on large-capacity 5.25" drives with Orca, a new American design house, but production languished at less than 1,000 units per month. Neither side was successful in marketing the output. Constrained by weak yield rates, a narrow product range and a flawed initial design,

the company lost more than NTD \$200 million of its initial capitalization of NTD \$300 million. In mid-1992 a “market-oriented faction” gained control of the board of directors of Magtron’s long-suffering lead investor Zhengfeng Chemicals and support for Magtron disappeared. Magtron soon declared bankruptcy and shifted production from Taiwan to mainland China, a classic response of Taiwan’s labor-intensive small firms to rapid increases in the island’s wages and land prices.²⁸

Taiwan’s second domestic producer, Greenery Technology (Maoqing) also sought a competitive advantage in low-cost, low-volume production rather than design innovation or marketing. The leading investment came from the family of general manager and former Qinghua University Professor Zhang Yuzheng, which owned a Toyota franchise in central Taiwan. Seventy per cent of the 80-odd staff members came from Taiwan Priam, which had fallen into difficulties. Greenery Technology purchased the rights to ITRI’s full-height, 2-platter, 3.5” 60-170 MB prototype but with limited capital and few in-house technical capabilities, it was unable to scale up production or keep up with rapidly increasing memory capacities. Greenery then attempted to negotiate a contract production agreement with Rodime, a British firm that had pioneered production of 3.5” drives, but before the deal could be consummated Rodime collapsed.²⁹ Stuck with outdated designs, in December 1991 Greenery Technology also failed. In September of 1992 it attempted to reorganize as Jinyi Technology and contracted to utilize ITRI’s new generation of 3.5” 240MB and 2.5” 120 MB drives, but was unable to put them into mass production. The company ended up selling its production equipment to mainland China.³⁰

The strategy adopted by the final domestic producer, Zentek, was technologically ambitious but commercially conservative. Zeng Jiandu, the head of Longshine Electronics (Longxiang), a small manufacturer of hard disk controller

cards, established Zentek (Hongyi Keji) at the end of 1989, with additional investment from Universal Scientific Industrial (USI; Huanlong Dianqi), a mid-size producer of electronic parts and packaging for autos and computers. After receiving a master's degree in electrical engineering from National Taiwan University, Zeng served for a time as a manager in the research division of Mitac (Shentong), one of Taiwan's largest computer makers, before setting up Longshine in 1981. Zeng was well connected and closely attuned to the government's increasing desire to promote the hard drive industry. Zeng served on the board of the Taipei Computer Association, the leading private association in Taiwan's computer industry and as a member of the Ministry of Economic Affairs' Information Industry Development Strategy Committee. In the early 1990s Zentek's staff totaled about 160, including 28 in the research division, some of them located in a Silicon Valley design subsidiary headed by an Indian engineer.

With only NTD \$150 million in initial capital Zentek avoided mass production. Instead, it attempted to implement a strategy of small lot production of a wide range of designs acquired from a variety of sources. Zentek based its first models on prototypes of 3.5" by 1.6" 60-100 MB (later 80-120 MB) drives designed by ITRI's Opto-Electronics and Systems Laboratories (Guangdiansuo), which had taken over responsibility for hard disks from ERSO. In July 1989, even before formal incorporation, the company dispatched seven engineers to ITRI to work on development of the prototypes. Like Magtron, Zentek signed a strategic alliance with the American design house Orca, which promised to buy 50,000 units in the first two years, while Zentek was free to market the rest on its own. By early 1992 it produced 3.5" by 1.6" units with capacities of 330 or 430 MB. Yield rates were under 70%, significantly lower than in Singapore and dramatically different from Taiwan's

semiconductor industry, whose mass-production techniques achieved yield rates significantly higher than those in former leader Japan. The company exported small lots to backward markets such as the Ukraine, Latin America and mainland China. The company boasted that its break-even point of only 2,400 units per month was far lower than those of its American competitors—but it produced fewer than 1,000 units of the two models, far less than its break-even point. Zentek independently designed a 3.5", one-inch high unit with a capacity of 120MB, cooperated with ITRI on development of a 2.5" by 0.75" 80MB drive and acquired Epson of America, which had developed a 2.5" by 0.75" 42 MB removable unit. Zentek also worked with ITRI on development of CD-ROM drives.³¹

Despite its superior technological capabilities, Zentek, like the other hard disk producers in Taiwan, was consistently late to market. Delays were not simply the product of technological incompetence. Zentek's strategy of low-volume, low-cost manufacturing created an intractable dilemma in coping with the extraordinarily short product cycles characteristic of the hard disk drive industry. Producers of key parts, most of them located in Japan, charged high prices at the beginning of the product cycle and preferred to supply their largest and most reliable customers first. They were also reluctant to modify their initial designs to accommodate the needs of Taiwan's small firms. Constrained by limited capitalization, Zentek and the other producers in Taiwan preferred to cut costs and limit risks by waiting until the next generation of equipment stabilized technically and reached a reasonable price. But by delaying production Taiwan's producers missed out on the most lucrative part of the product cycle. By the time they began production, the prices they could charge were low and margins extraordinarily tight, if indeed any margins were left at all. The famed flexibility of Taiwan's small electronics producers failed to apply to an

industry like hard disks in which both the basic architecture and the key parts were in a constant state of flux. Zentek finally caught up with the product cycle in late 1994, but by then the company was financially exhausted and incapable of sustaining mass production.³²

Figure One
Hard Disk Producers in Taiwan

FIRM	Entry	Exit	Capital	Investors	Source of Technology
Tatung (Datong)	c. 1982 (but never mass produced)	Late 1980s	NA	Old-line electronics firm	1. Contract production for US company 2. ITRI
Cogito (Gaozhi)	1984	1987	NTD \$200 million (1984) (NTD one billion from Taiwan for US mother company)	DFI from returnees; Chinfon [Qingfeng] Group	1. Magnex (US)
Taiwan Priam (Puan)	Late 1986	1990	NTD \$150 (1988)	DFI from Priam Systems of Silicon Valley	Mother company in Silicon Valley
Microscience International (Taiwan Weike)	1986	1992 (January)	NTD \$460 million	DFI from Microscience International of Silicon Valley; Acer Computers; Formosa Plastics	Mother company; Siemens
Magtron (Yongjin)	1989	1992 late	NTD \$300 million	Zhengfeng Chemicals	1. Central Data 2. Orca
Greenery Technology (Maoqing)	1989.10	1991 (December)	NTD \$140 million	Toyota distributor for central Taiwan	ITRI
Zentek (Hongyi Keji)	1989.12	1998	NTD \$150 million (soon increased to NTD \$300 million, then to NTD \$500 in mid-September 1992, and in January 1997 to NTD \$1.2 billion)	Universal Scientific Industrial; Longshine Electronics; later Bank of Communications, KMT's China Development and Three Six Construction	1. ITRI; 2. Orca 3. US subsidiary 4. Acquisitions

NOTES: Reports on size of capital and dates of establishment vary slightly. "Entry" refers to acquisition of designs and establishment of a hard disk production facility, not necessarily production, much less shipments. "Exit" means shuttering of production facilities.

SOURCES: III *Nianjian* 1992, p. 86, 1993 p. 207; *Gongshang Shibao* October 25, 1992; *O&I* March 1992, pp. 41-48, Shih-Chang Hung, Chu-Tao Wu and Yee-Yeen Chu, "National Systems, Technology and Industry Development: A Case Study of Taiwan's Monitor and Hard Disk Drive Industries," Paper submitted to Workshop on A New Technological Landscape in Asia Pacific, March 11-12, 1999, Taipei, ROC; supplemented by other reports.

Figure Two

Magnetic Disk Drive Production in Taiwan

Year	Production (units)	Exports (units)	Production (USD)	Export Value (USD)
1982	5,500 (FDD)			\$0.5 million
1983	181,000 (FDD)			\$15 million
1984	934,000 (FDD)	901,000		\$86 million
1985	364,000 (FDD)	549,000	\$51 million	\$46 million
1986	563,000 (FDD)	715,000	\$79 million	\$71 million
1987	666,000 (FDD + HDD)	654,000 (HDD: 49,125)	\$99 million	\$97 million
1988	805,000 (FDD + HDD)	800,00 (HDD: 172,226)	\$124 million	\$119 million
1989	1,055,000 (FDD + HDD)	950,000 (HDD: 139,191)	\$174 million (HDD: \$70 million)	\$157 million
1990		HDD: 160,150	\$69 million	
1991		HDD: 65,200	\$56 million	
1992	16,926 (HDD)	9,550	\$7.6 million	\$3.6 million
1993	25,526 (HDD)	21,326	\$3.8 million	\$3.0 million
1994	7,760 (HDD)	3,829	\$1.3 million	\$0.9 million

SOURCES: Statistics on hard disk drives must be seen as approximations, especially for the early years. Since hard disks never became major products, the government and market analysts did not cover them closely. Moreover, statistics in early years often fail to distinguish clearly between floppy disks and hard disks. 1982: *Dianzi Nianjian*; 1983-84: Electronics Taiwan, *ROC Information Industry Yearbook '86* (Taipei: CENS, 1986), p. 30; 1985-1988: III/MIC, January 1989; 1989: Zixun Gongye Cejinhui [III], *Zhonghua Minguo 78-nian Zixun Gongye Nianjian* [Yearbook of the Information Industry of the Republic of China] (Taipei: Zixun Gongye Cejinhui, 1989), 270; 992-94: Taiwan Jingji Yanjiuyuan, *Zhonghua Minguo Zixun Dianzi Gongye Nianjian 84* [Almanac of the Information and Electronics Industry of the Republic of China 1995] (Taipei: Taiwan Jingji Yanjiuyuan, 1995), p. 268; HDD Exports, 1987-90: *O&1*, March 1992, p. 42; 1989-91 HDD output value: III, *Information Industry Yearbook, Taiwan, ROC* (Taipei: III, 1992). Where necessary, NTD converted to USD at year-end exchange rates given in Council on Economic Planning and Development, *Taiwan Statistical Data Book 1998* (Taipei: Executive Yuan 1999), p. 166

PARTS PRODUCTION IN TAIWAN

Taiwan possessed a stronger and more diversified industrial base for electronics parts and fostered the development of more indigenous hard disk parts firms than any other Asian country outside Japan. Local firms proved readily capable of producing some of the simpler parts and related components, such as aluminum substrates and controller cards. Nevertheless, some parts presented significant technological challenges and even parts suppliers who surmounted technological obstacles withered when Taiwan's final assemblers proved unable to reach economies of scale. As a result, despite Taiwan's clear technological lead over Southeast Asia and even Korea, its hard disk parts industry never matched those of Singapore or Malaysia. Foreign investors did not enter and the parts industry eventually withered away.

Existing electronics makers who depended on Japan for technology sometimes were unable to supply more complex parts for the hard disk business. The Taiwan subsidiary of TDK, for example, manufactured magnetic heads in large quantities for other applications, but attempts to sell its Japanese-designed hard disk heads failed because local assemblers demanded adherence to the technical specifications established by the American-Singapore production complex. Given Taiwan's small production volumes, it did not pay to invest in modifying the specs. Similar problems plagued Teco Electric (Dongyuan Dianji), a motor maker with technology ties to Japanese companies such as Mitsubishi Electric.³³

The combination of daunting technological challenges and inability to attain scale economies deterred many would-be new producers. In the case of ASIC chip sets, local semiconductor firms found little attraction in the limited quantities

demanding by the hard disk industry when their other businesses were expanding at extraordinary rates. Taiwan Semiconductor Manufacturing Company produced some sets in the early 1990s, but local semiconductor firms generally ignored hard disks.³⁴ As for magnetic read-write heads, one of the most technologically demanding parts in hard disk drives, ITRI actively conducted research, gained patents and created a number of prototypes.³⁵ The government-owned Chiao Tung Bank (Jiaotong Yinhang, formerly known as the Bank of Communications) tried to encourage overseas Chinese to return and establish startup firms to commercialize heads. In the early 1990s, as Microscience, Magtron and other assemblers expanded operations, a number of venture outfits announced plans to produce magnetic heads. As late as 1997 Trace Storage, Taiwan's only manufacturer of 3.5" magnetic platters, received a subsidy from the Ministry of Economic Affairs and entered an international strategic alliance with major overseas makers to develop new heads. In each case, however, firms backed off in the face of uncertain demand and technological barriers created by product cycles that declined to well under a year.³⁶

For a time, local firms were able to establish a significant production presence in two important areas: motors and platters. The establishment of hard disk assemblers in the late 1980s and early 1990s and the active promotion of hard disk-related technology transfer from ITRI encouraged new investors to begin volume production of such critical parts as magnetic metal platters and spindle and stepper motors.³⁷ Shengbao, a major consumer electronics firm, produced stepper motors, used to position the magnetic read-write heads in the proper position just above a platter. Two smaller firms, Haien Jinshu and Huanlong Keji (a sister to Huanlong Dianqi, one of the investors in Zentek) produced an alternative product, voice coil motors.³⁸ For a time they supplied local assemblers.

More intriguing and longer lived was Mototech (Xingjiandong), one of only five manufacturers in the world, and one of only two outside Japan, of the brushless DC spindle motors used to drive metal platters. In 1988 a PhD returnee from the U.S. teamed up with the founder of Taiwan Microscience and one of the Japanese founders of Shinano Tokki, a major Japanese manufacturer of spindle motors soon to be acquired by global leader Nidec, to create a local source of supply. Such direct participation by Japanese engineers was rare in electronics (though not unknown in Taiwan's auto and steel industries). After some initial successes, in May 1991 the company fell into a financial crisis. Central Holdings, a financial arm of the ruling Kuomintang (KMT) party, rescued the company as part of its drive into high tech investments. In 1993 Central Holdings invested an additional NTD \$100 million and in 1994 it replaced the Japanese-dominated technology team with locals. Mototech managed to win some significant orders to supply European and American customers, including Quantum, but it was burdened with a backlog of debts and constrained by the collapse of local assemblers. In 1995 the company cut its capital by 95%. In 1996 the Accton Technology group (Zhibang) took a controlling investment. Mototech moved into production of hub switching equipment for local area networks, which soon accounted for two-thirds of its annual revenue of around USD \$50 million. The company continued to produce motors, but it largely abandoned hard disks and instead targeted scanners and CD-ROM drives, products for which ample demand emanated from the Taiwan producers that came to dominate global production.³⁹

A similar pattern unfolded in platters. Two firms manufactured platters, while three others drew up plans, only to drop them in the early 1990s. The President Group, one of Taiwan's largest manufacturers of food products and owner of the

island's immensely profitable 7-11 franchise, invested in Kaitek Media (Kaide), a producer of large oxide platters. Kaitek, founded in San Jose by a Taiwanese investors, was extremely successful at first, earning back its entire invested capital in the first year, but it proved incapable of keeping up with rapid advances in recording density and new products such as sputtered disks and began losing money. It acquired a thin film platter producer in the U.S. but aborted plans to produce 3.5" thin film disks in Taiwan. Within four years it closed its doors.⁴⁰ Zhonghua Ciji, a producer of aluminum substrates for hard disk drives, also responded to the entry of new assemblers by drawing up plans to acquire British and American aluminum platter companies, but abandoned its plans when it was unable to attract enough investors.⁴¹ From outside the industry, Guoju Dianzi, a mainstream producer of electronic parts, announced plans to build platters in 1990 but soon gave up.⁴² Kaifa Keji, an arm of the KMT's China Development group, invested in foreign platter producers and announced plans to transfer the technology back to Taiwan, but soon aborted its plans.⁴³

Only one local platter firm established a significant presence in the global hard disk drive industry. In September 1990 Wu Chuntai, a top executive in the Chinatrust Group (He Xin Jituan, also known as Koo's Group after the surname of the leading families), brought together a group of returnees from the U.S. to establish Trace Storage Technology (He Qiao) to produce Taiwan's first 3.5" platters. Even more than the President Group, Chinatrust, led by Koo Chen-fu (Gu Zhenfu) and his nephew Jeffrey Koo (Gu Liansong) long enjoyed intimate ties with the government. Wu had helped Chinatrust reorganize the failing petrochemical company Dadechang into Guoqiao Petrochemicals and shepherded its successful launching on the stock

market. Now he led the group's push into high technology industries. Wu himself took a major stake in the new company (28.84% as of 1997).

From the beginning Trace Storage relied heavily on research support from ITRI's Materials Laboratory (*Cailiaosuo*). This was not surprising. Private firms in Taiwan were much weaker in materials than in electronics. Moreover, in the early 1990s the head of the lab was the distinguished researcher Wu Bingtian—Wu Chuntai's older brother. Trace signed an eighteen-month contract with the Materials Laboratory covering planning, technology and engineering. Upon completion of the first factory in February 1992 Trace signed another contract for two years. That year the company also received a subsidy from the Ministry of Economic Affairs to develop innovative products, in this case, high-density platters. Trace Storage's first products, 3.5" sputtered platters with recording densities of 1200 Oe and 1400 Oe, appeared in June 1992. At first both products and output lagged behind plans and market trends. In its first two and a half years the company lost heavily. In 1994 the company was forced to cut its capital by 80% and recapitalize. Chairman Wu Chuntai convinced his older brother, who had left ITRI to head Asia Chemicals, to take over as Trace's General Manager. Wu Bingtian managed to ramp up capacity and steer the company into the black. In mid-1994 Trace acquired Oerdex of Fremont, California and turned it into an American research base. In 1995 the company tripled the research and development staff. In 1996 it received a USD \$72.5 million dollar loan from a consortium of financial firms led by Chinatrust and the KMT's holding companies to initiate construction on a new factory to produce aluminum substrates and more platters. By 1997 Trace Storage was far larger than any of Taiwan's hard disk assemblers had ever been, with a staff of 1200 and a research department of 117, including 15 PhDs. Trace supplied platters to three of the world's top five hard disk

drive producers. The company's annual output of nine million platters made it the world's tenth largest independent supplier. Though still smallest of the major suppliers, its products accounted for 5% of total world output.⁴⁴ Trace's prospects looked bright. Wu Bingtian convinced the vice-chair of ITRI's Materials Laboratory to join him and serve as Trace's research director. The company received research grants from the Science-Based Industrial Park, the National Science Council and the Ministry of Economic Affairs to develop new products such as magneto-resistive (MR) platters and heads. Trace entered a research alliance with major foreign hard disk drive suppliers to optimize the match between MR heads and platters.

Unfortunately for Trace, it proved unable to keep pace with the ever-decreasing product cycles of the hard disk industry. The company began to lose money and by the end of the year its debt-equity ratio had increased to nearly 4:1—on a par with the leading Korean *chaebol* on the eve of the financial crisis. In 1998 the company lost nearly USD \$89 million dollars—almost equal to its paid-in capital. General Manager Wu Bingtian resigned for reasons of health and the company dismissed one-third of its work force. Trace's stock price, once over NTD \$100, slid below face value at less than NTD\$10.⁴⁵

Figure Three
Major Hard Disk Drive Parts Producers

Magnetic Platters	Spindle Motors	Voice Coil and Stepper Motors	ASIC Chip Sets	Magnetic Heads
Trace Storage (Heqiao Keji) Sputtered thin film platters: major producer, but only intermittently profitable	Mototech (Xingjiandong Jingmi): major producer for several years but eventually shifted to scanner motors and networking products	Huanlong Keji (VCM) Produced for a time but dropped out by 1992	Taiwan Semiconductor (TSMC) Limited production in early 1990s	ITRI: prototypes
Kaide Large oxide platters; acquired thin film platter producer in U.S. but aborted plans to produce in Taiwan		Haien Jinshu (VCM) Produced for a time but dropped out by 1992		Trace Storage: received subsidy from MOEA for research (1997) and entered strategic R&D alliance with Read-Rite, SAE/TDK, AMC, but financial problems made commercialization difficult
Zhonghua Ciji Produced aluminum substrates; bought failing English platter producer Eurodisk, but aborted plans to produce thin film platters in Taiwan after failing to raise sufficient capital		Shengbao (stepper) Produced for a time but dropped out by 1992		Kaifa Keji KMT affiliate acquired Silicon Valley thin film magnetic head producer Dastek but aborted plans to produce in Taiwan
Guoju Dianzi Aborted plans for thin film platters				Chengxin Venture Capital planned investment aborted after industry slowdown in early 1990s
Kaifa Keji Aborted plans for thin film platters				

SOURCES: III, 1992 *Nianjian*, p. 87; *Chanye Jingji* 152 (April 1992), p. 17; *0&I*, June 1992, p. 257; *Caixun* November 1995, pp. 280-87; *Jingji Ribao*, September 4, 1990, January 18, 1991, August 4, 1992; *Gongshang Shibao*, October 4, 1990, October 25, 1992; Trace Storage, October 1998, at <www.caita.com.tw/award/97-10.htm>, accessed 2 September 1999

LIMITED BAILOUTS

For a time it seemed as if hard disk drives would become another success for Taiwan's electronics industry. Even without vigorous promotion by the government, a number of assemblers and producers of key parts established operations in Taiwan

from the late 1980s through 1990. However, beginning in the second half of 1990, a two-year recession descended on the industry. Global demand did not just shift to new products but for the first time since the emergence of the personal computer actually suffered an aggregate decline. American firms reacted by accelerating their move to higher-density products. Price cuts on their older products then created a crisis in the chronically weak and late Taiwan HDD industry.

Ironically, the first steps toward possible mergers and bailouts were stimulated by the apparent success of the industry. In 1990 Central Investments, one of the KMT's main holding companies, investigated the possibility of establishing a large new hard disk assembler. Existing producers, frightened by the prospect of a new competitor with deep pockets, began to explore merger possibilities. As the industry moved into recession, the National Science Council asked Central Investments to consider investing in a merger of local companies rather than setting up a new firm. Despite the increasingly severe economic environment, mergers were by no means easy to engineer. Magtron still enjoyed the support of Zhengfeng Chemical while Zentek was just beginning operations, so it had not suffered much from the recession. Both preferred to maintain autonomy rather than merge with failing partners. Greenery Technology initially sought salvation from the British firm Rodime and only looked to local merger possibilities when Rodime failed. Thus only Taiwan Microscience and Greenery were receptive to the possibility of merger, but Central Investments balked at Taiwan Microscience's excessive debts and by late 1991 the plan stalled. Failing to attract support, Greenery Technology suspended operations at the end of 1991, while Taiwan Microscience went out of business in January 1992.

The government refused to invest directly in the industry, but made it clear that it would provide technological support for serious efforts by local firms. In late

August ITRI's Opto-Electronics and Systems Laboratories helped transform the industry's HDD Industry Club (Yingdieji chanye julebu), composed of nine up-mid- and down stream firms, into the Hard Disk Drive Industry Strategic Alliance (yingshi cidieji gongye (celue) lianmeng). Later in the year the National Science Council announced that it was placing hard disks on the list of industries it intended to promote and making space available in the next phase of the expansion of the Science-Based Industrial Park. The quasi-governmental research organ III (Institute for the Information Industry), talked of including hard disks in its "diamond plan." Zentek, Magtron and Greenery separately applied to the leading products fund of the Economics Ministry to produce 2.5" drives. Under this scheme IDB supplied half of the financing necessary to design "leading products" (*zhudaoxing chanpin*) and provided low-interest loans to cover the other half. The MOEA's Industrial Development Bureau (IDB) indicated that local firms should concentrate on cooperation first before talking of using government support and suggested that they establish an R&D alliance. Once again, tensions among the firms prevented action. The IDB then separately contracted with Zentek, the local firm with the strongest design capabilities, to develop a proposal for a vertical alliance with major suppliers such as Trace Storage Technology and Mototech to create new 2.5" inch drives. In either case, the IDB's support would have remained limited to about NTD \$ 100 million dollars (a little less than USD four million dollars). IDB resisted pressures from the industry to instruct government-controlled banks to supply preferential lending to the industry.⁴⁶

The government's increased commitment to the hard drive industry also attracted the interest of potential foreign investors. In January 1992 the American hard disk maker Integral applied to invest in the Science-Based Industrial Park to

produce 1.8” drives and sought the government’s help in procuring land and financing. The company had applied in August of the previous year but had withdrawn on the grounds that the Park was too full and announced that it would look at Singapore. After it discovered that Singapore would no longer provide low-cost loans for the well-established hard drive business, it came back to look at Taiwan. Another American firm, Orbiter, made similar announcements. However, though the government was now willing to make space available in the Park, it did not meet the companies’ requests for preferential financing.⁴⁷

The National Science Council joined with ITRI’s Opto-Electronics and Systems Laboratories, which had just developed a new generation of hard disk prototypes (3.5” x 1.0”/240 MB and 2.5” x 0.75”/120 MB, 16ms access time and 2500 TPI density), in a plan to bring together the existing producers and the would-be foreign investors in a new firm that would be eligible for government funding and tax breaks. The NSC revealed that it was willing to put in as much as NTD \$100 million dollars, and hired a venture capital firm to raise another NTD \$900 million from computer and electronics companies. In principle, Acer, Taiwan’s largest computer company, supported the idea of creating a competitive local hard disk firm in order to reduce the uncertainties and delays involved in importing hard disks from Singapore (the newest way to speculate in futures, as Acer put it). However, Acer had been burned by its investment in Taiwan Microscience and would not invest without stronger financial support from the government. Other computer firms were even more skeptical. Greenery Technology, by then reorganized as Jinyi Technology, signed a new contract to acquire ITRI’s new prototypes for NTD \$10 million dollars. However, at the last minute its funding fell through. Magtron fled to the mainland, while the American firms abandoned plans to invest in Taiwan. For its part, Zentek

was not interested in transferring ITRI's new prototypes because it was about to complete development of slightly smaller capacity models of its own. Without a commitment from the Industrial Development Bureau to provide a much greater share of financing, the idea of forming a single new firm was doomed.⁴⁸

Attention then shifted to Zentek, the sole remaining hard disk producer. Zentek was unique in having concentrated not on production technology but on amassing design experience in a wide range of products. It also made a special effort to incorporate parts from Taiwan. This approach greatly appealed to policymakers concerned about the lack of independent hard disk technology in Taiwan. The Chiao Tung Bank, Taiwan's main development bank, and the KMT's China Development Corporation invested small amounts in Zentek. The downside of concentrating on design rather than production was that Zentek suffered weak yields and lacked cash flow. Once it began volume production the company quickly needed to increase its capitalization. By early 1993 all other producers had exited the market and Zentek approached the Industrial Development Bureau about financing. IDB, however, was cautious. ITRI project engineers expressed frustration at legal restrictions that prevented the government from investing directly in Hongyi to support its efforts at mass production.⁴⁹ In January 1994 Zentek and ITRI's Opto-Electronics Laboratory presented a development proposal to IDB. In response to the Bureau's request for a more detailed feasibility report, Zentek readied a plan to increase the company's capitalization from the current NTD \$500 million dollars to NTD three billion dollars. Zentek hoped for NTD \$200 million in support from the government's leading product development fund and loans from government banks. Even with this support, the company would need to raise the remaining NTD \$2.3 billion from private

sources. Given the past record of the hard drive industry in Taiwan and the government's limited, cautious response, no such funds were forthcoming.⁵⁰

For a moment it appeared that the government's dream of a concerted effort in hard disks by the private sector would finally bear fruit. In the fall of 1994 Asia-Pacific Investment Company announced that it would engage in five major technology projects to overcome the limits of Taiwan's traditional firms. Hard drives headed the list. Originally planned as a public-private joint venture, the new company eventually became an arm of one of Taiwan's largest and best managed conglomerates, Formosa Plastics. Its general manager, Wu Huiran, was a former assistant director of the Industrial Development Bureau. The holder of a PhD in agricultural economics from Tokyo University, Wu was a big fan of Japanese industrial policy.⁵¹ He announced a joint venture with the American computer giant Hewlett-Packard, long a major investor in Taiwan, to invest NTD \$3.5 billion dollars in a large hard disk factory. Despite Wu's enthusiasm and his ability to entice a credible partner, the plan failed to pass the muster of Asia-Pacific's financial analysts and quickly died.⁵²

Relieved from the threat of entry by an overwhelming opponent, Zentek renewed its lobbying efforts. The Ministry of Economic Affairs, increasingly worried about the failure of the domestic hard disk industry and declining rates of private investment in Taiwan, expressed its willingness to support the company's expansion plans with funds from the Executive Yuan's development fund and the Chiao Tung Bank. Before committing any funds, the IDB asked Zentek to provide evidence that it could attract private investors, strengthen its management capabilities and secure a foreign source of technology. This request placed Zentek in a bind: without a positive record it could not receive support from the government, but without adequate capital

it could not sustain operations and keep up the relentless pace of development on new products. Despite rapid expansion of production that more than doubled revenues in 1995 to NTD \$270 million, Zentek was unable to pull out of the red. By 1996 the company suspended production. With support from the Industrial Development Bureau it finally succeeded in raising NTD \$700 million dollars through the issuance of new preferred stocks in the spring of 1997, bringing total capitalization to NTD \$1.2 billion, still far from its original goal of three billion dollars. It did not enter a strategic alliance with a foreign firm but brought in a group of returnees, including a new general manager. It announced plans to mass-produce two new products: a 1.5 GB 3.5” drive and a 100 MB removable cartridge designed to compete with Iomega. Despite these brave new plans, the company was never able to attract sufficient capital to reestablish production. Far from providing unconditional support, the government premised even its small investment on numerous improvements. Even then, the government’s own Chiao Tung Bank, owner of 8% of Zentek’s stock, fatally undermined its already shaky reputation by repeatedly expression its reservation at Zentek’s failure to present fully audited financial statements. As of mid-1999 the company’s small plant in the Science-Based Industrial Park stood dark and shuttered. The single old watchman reported that the company’s management was still trying to decide how to make a comeback.⁵³

In 1996-97, as in 1991-92, the signs that the government was willing to provide some financial support to the hard disk industry attracted potential foreign investors. JTS, a supplier to Compaq, announced that it planned a joint investment with the venture investment arm of the Yulong group (the local assembler of Nissan automobiles) and the Singapore government to establish a USD seventy million dollar

assembly operation for 3” hard disks in Taiwan.⁵⁴ Once again the government failed to respond with aggressive policies and the plans died away.

In response to the failure of domestic producers and the inability to attract foreign investors, the government switched tactics. The Council for Economic Planning and Development and the Economics Ministry developed a plan to encourage foreign companies to place their East Asian regional operations centers in Taiwan. After upgrades to transportation infrastructure and major revisions to customs procedures, tax laws and regulations on direct foreign investment, Taiwan was able to attract major investments from UPS, FedEx and other shipping companies in 24-hour transshipment facilities. One of the major targets: hard disk drives.⁵⁵ Thus, rather than solving the dilemma faced by local computer companies that did not have ready access to hard disks by enticing local or foreign firms to produce them in Taiwan, the government eventually helped ameliorate the problem by speeding access to disks produced elsewhere.

MOVING BEYOND FAILURE: THE PROMOTION OF CD PRODUCTS

In CD-related products, just as in the hard disk drive industry, the government provided extensive technical support and occasionally subsidized development of specific new products without investing in (or directing government banks to support) particular producers. The results, however, were dramatically different. In just a couple of years firms from Taiwan wrested the world market for CD-ROM (compact disc, read-only-memory) disks from Japan and Europe. Taiwan’s firms also became the world’s largest suppliers of CD-ROM players, pulling far ahead of Singapore and South Korea to surpass Japan. In the emerging area of CD-ROMs that can be recorded once (CD-R) or rewritten a thousand times or more (CD-RW) production in

Taiwan rapidly approached that of market leader Japan, again pulling away from Korea and Singapore. Success in CD-related products also primed Taiwan to play a role, albeit much more modest, in the long-awaited next generation of Digital Versatile Disks (DVD), which can record seven to twenty-eight times as much material as CD-based products.

CD-ROM and associated products played much better to Taiwan's strengths than did hard drives. The leading producers were highly focused small and medium-sized firms, with support from ITRI, the Ministry of Economic Affairs, a stock market focused on electronics companies and an emerging venture capital market. When CD-ROMs emerged in the early 1990s, the average size of CD producers around the globe was 5-10 per cent that of HDD firms. Many of the leading producers were large Japanese electronics firms such as Sony, Toshiba and NEC, but unlike the case of hard disks, the industry also had room for dozens of smaller producers.⁵⁶ CD-ROM disks and players, in other words, looked far more like Taiwan's successful computer and semiconductor sectors than its failed hard disk industry.

Four factors served to reduce the barriers to entry that had proved so difficult for Taiwan's small and medium-sized hard disk producers to overcome. First, CDs utilized simpler, more stable technology. CD-ROMs built upon the compact disk technology developed by Philips and Sony to replace the phonograph record. After the introduction of CDs in 1980 and CD-ROMs in 1983, their capacity was virtually fixed at 640-680 megabytes. Compatibility of was far more important for CD-based products. Unlike the vast majority of hard disk drives, which stayed fixed within a computer, CD-ROM disks were routinely transferred from machine to machine. Even when newer and faster CD-ROM drives appeared, they had to maintain backward compatibility with older machines to play existing disks. International committees of

electronics engineers enshrined format standards for each of the spin-offs from the original CD in specification books, such as the “yellow book” for CD-ROMs, and several volumes of “orange books” for CD-R and CD-RW.⁵⁷ Second, the information stored on CD-ROMs was rarely essential to the day-to-day operation of a user’s computer. If a CD-ROM drive failed, the user could still use her computer and access her data, but if a hard disk crashed, all but the most disciplined and well-backed-up users would lose some or all of their data and programs. Concerns for quality and after-sales service were thus less of an obstacle in the case of CD-ROMs. Third, the price-sensitive consumer market proved surprisingly important for CD-ROMs, which were often used for games and other non-business applications. Home electronics users were less demanding of innovative capacities, reliability and service networks, and bought their products through retail outlets already thoroughly geared to procure electronics goods from Taiwan. Finally, the failure of DVD players to take off as quickly as expected created an opening for Taiwan’s CD-ROM producers. Japanese electronics firms sold key parts for CD-ROMs thinking that DVDs would quickly supplant them. When they failed to do so, the Japanese found that they had armed their most dangerous adversaries.

As with hard disk drives, the Industrial Technology Research Institute played a crucial role in developing and diffusing local technological capabilities for CD-ROMs. Indeed, it initiated research on optical disks a decade or more before private firms began production.⁵⁸ In August 1982 the government included opto-electronics in its list of eight key (*zhongdian*) industries. By 1984 ITRI and other agencies were working on optical projects including optical disks. In August 1987 ITRI gathered all opto-electronics activities in a single center. The next year it began work on optical disks with funding from the “special projects” plan of the Ministry of Economic

Affairs. In January 1990 ITRI promoted the center to a full Opto-Electronics and Systems Laboratory. The Lab completed a prototype of a 5.25" writable CD-ROM drive in March 1991, including read-write head, IC servo, controller cards, and chassis. It transferred some technology to local firms, but few were active in opto-electronics at that stage.⁵⁹ ITRI also received funding from the MOEA's Industrial Development Bureau for more specific, product-oriented plans under the "leading product" scheme, which was incorporated into the "key parts development" plan formulated in 1991. By 1992 the Laboratory actively carried out CD-ROM development with support from three five-year development plans funded by MOEA: opto-electronics technology and applications; optical information technology; and key parts and components.⁶⁰ The five-year plans resulted in the development of every type of CD-related product and all of the major components, including 2x, 4x, 6x and 8x speed CD-ROM drives and Video-CD players, as well as read-write heads, IC chip sets, spindle motors and other key components.⁶¹

The Opto-Electronics and Systems Laboratories switched emphasis from hard disks to CD-ROM drives and related products in 1993. The global hard drive industry fell into a recession that led to a wave of bankruptcies and mergers, further consolidating the position of the top few producers and making it increasingly obvious that the hard disk drive industry in Taiwan was beyond salvation. Though the CD-ROM industry was much smaller, it was growing rapidly and provided opportunities for Taiwan's small and medium-sized manufacturers. The Lab took the initiative in establishing an opto-electronics industry association. It transferred opto-electronics technology to over 20 local firms and provided engineering consulting to even more.⁶²

ITRI's prototypes, parts, components and engineering and testing services played an important role in convincing Japanese firms to transfer technology to Taiwan earlier in the product cycle than they otherwise would have. When Japanese firms monopolized a technology they had a collective incentive not to sell the technology to other countries, particularly lower-cost sites such as Taiwan and Korea, until they had extracted monopoly rents and moved on to the next generation of products. By providing a committed and credible alternative supplier, even in limited quantities, ITRI effectively notified the Japanese that competitors in Taiwan would emerge whether they liked it or not, so they might as well break ranks and profit from selling the necessary parts.⁶³ In Korea, the significant R&D capacity of the giant *chaebol* conglomerates fulfilled a similar role, but they were less nimble than Taiwan's firms.

ITRI's efforts to accelerate speed-to-market were crucial for Taiwan's medium-tech, medium-cost firms. In the early stages of the product cycle, barriers to entry were too daunting, but if the Taiwanese firms waited too long, the product would become a completely standardized commodity and they would lose to the mass production capacity of the Koreans or to the rock bottom prices of Japanese and Korean subsidiaries producing in Southeast Asia or mainland China. The renowned ability of Taiwan's electronics firms to succeed in rapidly moving niches, then, was not simply a function of their great speed and flexibility, but in significant measure a product of direct support and indirect tactical assistance from ITRI.

Taiwan's electronics firms first burst onto the CD scene with CD-ROM players. Local production did not even begin until 1994, roughly three years after Japan, but by 1996 Taiwan had captured 12 per cent of the global market. As prices declined, Japanese electronics firms stopped adding new capacity and OEM orders

from Japan came flowing into Taiwan. In 1996, Taiwanese electronics firms produced about half again as many CD-ROM drives as either South Korea or Singapore. By 1998 Taiwan produced twice as many units as Korea and thirty times as many as Singapore. Between 1998 and 1999 Taiwan's firms surpassed Japan as leading producers, with over 40% of global production. The industry was flexible, fluid and highly competitive. Entry and exit were frequent. The top half-dozen or so firms commanded 60-70% % of the market, but an additional twenty-odd firms, many of them brand new, survived on the periphery. Besides price, competition centered on speed. Soon CD-ROM players were operating at 24, 32 and even 48 or more times the data transfer speed of the original CDs. Product cycles for each "speed generation" declined from a year to six months to just three months. In the first quarter of 1998, two-thirds of the CD-ROM drives produced in Taiwan were 24x or slower while none exceeded 40x. In the second quarter, 1% exceeded 40x and in the third quarter 10%. By the fourth quarter fully 60% operated at forty times speed or higher; only two per cent were 24x or slower.⁶⁴

Local assemblers produced cases and controller cards and managed systems integration functions, but initially most of the key parts came from Philips or the Japanese electronics firms. By 1997-98, as plain CD-ROM players reached commodity status, local firms began transferring assembly to directly-invested plants in Malaysia and especially Dongguan in mainland China's Guangdong Province. The proportion of output from overseas rose from one-third in 1996 to nearly half in 1997 and almost two-thirds by the last quarter of 1998. The cost-cutting shift put inexorable pressure on prices and profit margins, as average unit prices (ex-factory) slid from USD \$64 in the first quarter of 1997 to USD \$49 in the first quarter of 1998 and just USD \$34 dollars in the first quarter of 1999. Nevertheless, while the niche

lasted, Taiwan's electronics sector benefited from extraordinary increases in production values and significant accretion of skills, including the ability to produce more sophisticated parts.⁶⁵

As standardization, scale economies and unrelenting price pressures pushed production of conventional CD-ROMs offshore, local firms increasingly emphasized production of CD-R and CD-RW, units capable of home recording or even rewriting. As with hard disks and CD-ROMS, initially local producers sold few of their units to Taiwan's thriving computer industry. Instead, their CD-R and CD-RW units appealed to foreign consumers seeking an inexpensive, convenient, standardized, and non-proprietary means of backup. In 1997, Taiwan accounted for 24% of world market share of CD-R drives. By the next year, over half (55%) came from Taiwanese firms. Taiwan producers also captured 37% of the global market for the more complex CD-RW drives and rapidly closed the gap with Japan. Through mid-1999 only about a half dozen of the largest firms were capable of producing CD-RW, including Mingji, Jianji, Yingqun, Taida, Guangyu, and Changgu. All of them reached licensed technology and purchased parts sets from Philips or Ricoh, a Japanese electronics firm best known for its copiers. At the same time, ITRI's Opto-Electronics and Systems Laboratory continued development work, completing a 6x write/2x rewrite model in early 1999 and transferring systems integration technology to local firms.⁶⁶

Figure Four
PRODUCTION OF CD-ROM DRIVES BY TAIWANESE FIRMS
(including an increasing proportion of CD-R and CD-RW models)

	1994	1995	1996	1997	1998 (prel.)	1999 (Oct. 1999 est.)	2000 (est. Dec. 1998)
Units	186,000	3.57 million	6.6 million	17.4 million	30.7 million	42 million	42.22 million
Production Value	USD \$16 million	USD \$196 million (est.)	USD \$410 million	USD \$863 million	USD \$1.486 billion		
Share of world production volume	1.1%	10%	12.1%	22.7%	34.4%	46%	56.1%

SOURCES: Calculated at an exchange rate of NTD \$35 = USD \$1. Based on ownership of production facilities rather than site of production or origin of designs. Thus, includes overseas production (largely in mainland China) by factories controlled directly by firms based in Taiwan as well as production in Taiwan under subcontracting arrangements with Japanese and other foreign firms. *Chanye Jingji* 164 (April 1995), pp. 90-91; *Chanye Jingji* 211 (March 1999), p. 58; *Chanye Jingji* 212 (April 1999), pp. 87-94. 1999 estimates: ITRI Opto-electronics and Systems Laboratories, as reported in *Zhongguo Shibao*, October 22, 1999

Taiwan's electronics firms made even more rapid strides in producing CD-ROM disks. While a few companies, such as market leader Ritek (Laide), began manufacturing plain disks in the late 1980s, a raft of firms entered the market from 1996 to 1999. With improvements in technology, the price per disk declined to five dollars from eight dollars. While Japanese companies refrained from expansion in the hope that DVDs would soon take off, CD-R disk production capacity in Taiwan exploded. In the space of a year, prices for CD-R disks, collapsed to less than a dollar. Like Taiwan's semiconductor fabrication foundries, the Taiwan CD-R companies beat the Japanese at their own game of high volume, high quality production. Japanese producers such as Mitsubishi Chemical had little choice but to exit the market and place OEM/ODM contracts with CD-R suppliers in Taiwan. In 1998 firms from Taiwan grabbed more than half of the global market; the next year their share headed toward 75 per cent. As prices declined, demand surged, doubling

between 1998 and 1999. Younger buyers downloaded large volumes of music from the Internet using the MP3 audio format and burned them onto the inexpensive CD-R disks. Other purchasers used the devices to serve as an all-purpose backup of digitized versions of all kinds of data, including audiocassettes, videocassettes, photographs and floppy disks.⁶⁷ At one point, Philips tried to use its formidable collection of intellectual property rights to slow the progress of the firms from Taiwan by filing lawsuits. In the end, however, it decided to join them rather than fight them, taking a minority share in a joint venture with Ritek to produce disks in Germany. The new venture complemented Ritek's extensive overseas production facilities in Australia, the United States and Ireland.⁶⁸ Similarly, CMC Magnetics (Zhonghuan), an established producer of videotape and 3.5" floppy disks that jumped into CD-R disks in 1997, entered into OEM agreements and strategic alliances with Pioneer and Mitsubishi Chemical.

As with CD-ROM players, initially most of the materials and production equipment to produce CD-R and CD-RW disks came from Philips and the Japanese. Fairly quickly, however, local firms began to produce the more sophisticated materials. ITRI and local firms put particular emphasis on the organic dyes whose phase changes made it possible to record information. ITRI provided technological support on dyes to CD-R producers such as Advanced Media Storage (Zhidie), while a group of former ITRI personnel established Gigastorage (Guoshuo) to produce (with continued engineering assistance from ITRI) both disks and the chemicals to produce them. ITRI itself transferred crucial technology to Echem (Xiangde), a joint venture it established with the local chemical firm Junxiang to produce over forty types of dyes for use in ever-faster CD-R, CD-RW and DVD-related disks.⁶⁹

As with CD-ROM drive producers—but completely unlike the situation in hard disks--the CD-R disk industry in Taiwan featured a large, varied and rapidly changing cast of players. The explosive growth of the CD-R business in 1998 and 1999 touched off a giddy run-up of stock prices that fueled the investment and growth of market leaders Ritek and CMC. These companies had no need of banks: with profit margins around 40%, retained earnings and offerings of corporate bonds and new stock funded their investments. Venture capital firms that had prudently warned the government not to become involved in hard disks poured funds into new CD-R companies such as Sean Tram (Xinqun) and Lidie. As the head of a venture capital firm with investments in Lidie proudly proclaimed, “The United States is far and away the leader in venture capital. Taiwan is number two. There is no number three.” While the venture capital firms were actually quite cautious about investing in completely new industries or even venturing beyond the electronics sector, when it came to offshoots of the Science-Based Industrial Park complex centered around Hsinchu, such as the CD-R companies, they had complete confidence.⁷⁰ Even with no support from venture capital, profitable new CD-R firms were able to list on the over-the-counter market just months after opening their doors. The contrast with the cautious venture capital industries in Japan and Korea could hardly have been greater.⁷¹

Figure Five

CD-ROM-RELATED DISK PRODUCTION BY TAIWANESE FIRMS

	1996	1997	1998
CD-ROM Disks: value	USD \$105 million	USD \$226 million	USD \$363 million
CD-R (recordable) Disks: units		47.5 million	345.3 million
CD-R (recordable) Disks: share of world market		24%	55%
CD-RW (rewriteable) Disks: share of world market			37%

SOURCE: Calculated at an exchange rate of NTD \$35 = USD \$1. ITRI
Guangdiansuo ITIS Jihua, *Dianzi Chanye Touxi*, December 1998, pp. 3-4; *Chanye
Jingji* 211 (March 1999), pp. 58-59

With profits from CD-ROM and CD-R drives and disks, Taiwan's electronics firms prepared to move into DVD products, an emerging market the Japanese were not about to abandon. Although they offered much greater capacity, DVDs did not attract buyers as quickly as originally anticipated. Technological uncertainty over the best approach for home recording and rewriting led to recurrent conflict over product standards. The absence of standards impeded attainment of economies of scale and confused consumers. Conflict also inhibited the creation of a unified system of intellectual property rights for DVDs. The many hardware and software firms from Japan, Europe and America that had contributed to the development of DVDs were determined to reap profits for their work even in the face of digital copying and the increasingly rapid diffusion of production technology, but they could not agree on how to do it. The sum demanded by the various patent holders, grouped in three different alliances, reached 10-15% per cent of the production price, far higher than the levels demanded for previous products. Not surprisingly, firms from Taiwan saw these charges as an indirect way of blocking them from the market. In the face of

these uncertainties and obstacles, they produced small quantities of DVD drives and disks, setting aside a portion of their revenue to pay royalties in the future.⁷²

In the meantime, ITRI served as a focal point for the local industry and represented Taiwan to the outside world in crucial areas such as the setting of DVD format standards. ITRI became one of seven members of the Steering Committee of the DVD Forum, along with six leading electronics concerns from Japan, the United States and Korea (Sharp, NEC, IBM, Intel, LG and Samsung—but not Philips or the five Japanese firms with the most direct commercial stakes in DVDs: Sony, Toshiba, Hitachi, Matsushita and Pioneer); by themselves, none of Taiwan's small and medium-sized DVD specialists had the technical or administrative capacity to deal on an equal basis with giant firms like IBM or NEC. With technical assistance from Matsushita, ITRI built the first Class A-DVD Verification Laboratory in Asia outside of Japan; only members of the Steering Committee had the right to establish A-class laboratories. Within the DVD Forum, ITRI's Opto-electronics and Systems Laboratories participated in eight different working groups on testing and certification. In two of them ITRI personnel served as co-chairs.⁷³ Domestically, ITRI sponsored a never-ending series of seminars and conferences on DVD. An industry association conference at ITRI in January, 1999, for example, attracted over 250 participants, including three legislators and Yang Shijian, Minister without Portfolio and former head of the MOEA's Industrial Development Bureau, as well as over twenty reporters. The Opto-Electronics and Systems Laboratories' calendar for May 1999 alone listed five major conferences on DVDs.⁷⁴

ITRI also promoted development and indigenization of DVD products, parts and materials. As of 1998, roughly 7% of ITRI's half billion-dollar budget, or about USD \$34 million, flowed to the Opto-Electronics and Systems Laboratories, much of

it for work on CD and DVD-related technologies. The Laboratories transferred systems integration technology for DVD-ROMs to fourteen local manufacturers, including a 5x DVD drive completed at the end of 1998. The Laboratories transferred to local firms technology for motors, decoders and demodulators and other key components for CD-ROM and DVD. At the end of 1998 they completed prototypes for three different types of pickup heads: complete image, traditional and slim version for notebook computers.⁷⁵ ITRI's venture incubation center also played host to Hongjing Keji, a joint venture established by Taida, Changgu, Hongyou and other DVD producers. In late 1999 Hongjing became the first firm in Taiwan to undertake mass production of read-write heads for DVD players.⁷⁶

Apart from supplying long-term funding R&D funding to ITRI, the Ministry of Economic Affairs also provided a few modest grants to support the development of new "leading projects" (*zhudao-xing kaifa jihua*). In FY 1998, for example, the Ministry provided a grant of about USD \$1.7 million dollars to local firm Hanping to develop fast, slim CD-ROMs for notebook computers and a little less to the startup disk firm Lidie to develop high volume DVD+RW drives.⁷⁷ In a few cases, local firms announced significant DVD-related innovations. Local IC design firms Zhiyang and Liansheng, for example, announced the completion of leading-edge chip sets for demodulation and error-correction in DVD-ROM drives.⁷⁸ Most firms engaged in new developments in DVD technology, however, received support from ITRI or the MOEA.

Taiwan's success in the demanding and rapidly moving world of DVD technology was by no means assured. As of 1998, Toshiba and Hitachi accounted for almost two-thirds of DVD-ROM production, while the Koreans made up three per cent and firms from Taiwan only one per cent. Nonetheless, if and when Taiwan does

come to assume a major role in DVDs, there is little doubt that the leading players will be small to medium-sized firms with good access to venture capital markets and restrained but ubiquitous support from ITRI's Opto-Electronics and Systems Laboratories.

Figure Six
Production of CD/DVD-related Disks

PRODUCT	STANDARD ESTABLISHED	FIRST PRODUCTION OF DISKS IN TAIWAN
CD (audio compact disk)	1980	
CD-ROM (compact disk—read only memory)	1983	1990
CD-R (compact disk-recordable [write once, read many times])	1990	1995
Video CD (medium definition video [MPEG I] plus compressed audio)	1993	
CD-RW (compact disk—rewritable)	1995	1996
DVD (digital versatile disk)	1996	1996
DVD-R (digital versatile disk—recordable; version one)	1997	1998
DVD-RAM (digital versatile disk—random access memory)	1998	1999

SOURCE: Xin Dianzi Keji Zazhi, *1999 Dianzi Gongye Shichang Nianjian* [1999 Yearbook of the Electronics Industry Market] (Taipei: Taibeishi Dianzi Lingjian Shangye Tongye Gonghui and Disanbo Zixun, 1999), p. 219; *Gongshang Shibao*, July 16, 1999 (CD-R Guangdiepian Zhuankan)

CONCLUSION

Even after a decade of concerted efforts by government and electronics firms, Taiwan failed to establish a viable hard disk drive industry to supply its

extraordinarily successful computer industry. The formidable barriers to entry in hard disks and the unremitting technological demands to increase recording capacity exceeded the capacity of Taiwan's research base and its small and medium-sized corporations. Moreover, unlike Singapore, Taiwan was unwilling and unable to attract the multinational corporations that could have kept pace with the rapid product cycles of the hard disk drive industry.

This failure vexed and embarrassed policymakers. Yet, in a broader perspective, the failure may well have been a blessing in disguise. Taiwan's approach to technological development avoided creating a white elephant industry that could have hampered the development of other industries and burdened the banks with bad loans (public aid to Zentek, Taiwan's last hope in the hard disk drive business, was so limited and short-lived as to constitute the proverbial exception that proved the rule). In 1993-94, as the hard disk drive industry fell into irretrievable decline, the government and local firms switched focus to a smaller but related and less demanding industry: CD-ROMs. In less than half a decade, the industry attracted dozens of firms, many of them startups. Taiwan emerged as the world's dominant supplier of CD-related drives and disks and a promising player in the slowly emerging DVD business.⁷⁹

The policies that contributed to these contrasting outcomes were not *laissez-faire*. On the contrary, the government planned and monitored incessantly, and provided technological support for both long-term development and specific innovative products. It strove to overcome infant industry dilemmas and to foster economies of scope. On occasion it even provided firms with small subsidies. However, the government exercised extreme restraint in directing the allocation of bank capital—even though the central and provincial governments controlled the bulk

of Taiwan's banking sector. Only the Chiao Tung Bank (Jiaotong Yinhang, formerly known as the Bank of Communications) was a development bank and it acted in a prudent and restrained fashion. Far from serving as an outpost of politicized statism, the Chiao Tung Bank boasted one of the lowest ratios of non-performing loan in Taiwan.⁸⁰ Moreover, perhaps unique among the world's development banks, it played the crucial role in fostering the development of a local venture capital industry, as even venture capitalists otherwise critical or dismissive of the government readily acknowledged.⁸¹ When the government asked the Chiao Tung Bank what to do about the hard drive industry, it consulted venture capital firms, who turned thumbs down. Far from bailing out the failing Zentek, the Bank publicized its dodgy bookkeeping practices. It is hard to think of a comparable case in Korea or Japan.

Taiwan's prudent and restrained approach to the allocation of capital conventionally has been attributed to the strength and relative autonomy of the ruling party, and no doubt this is correct, particularly before the early 1990s, when democratization began to affect the policymaking process.⁸² It is worth noting, however, that the ITRI model of strong state and small firms is more conducive to such an approach than the strong state-big conglomerates model of Korea or the intertwined government-business relations of Japan. The efforts of the ITRI and the Ministry of Economic Affairs to lower barriers to entry to local firms implied a proliferation of small firms and accordingly opportunities for alternative employment for those displaced by occasional failure. Neither large foreign investors nor conglomerates with widespread business contacts and political allies constrained policymaking. The Economics Ministry and ITRI were free to focus on new opportunities and ongoing successes (such as CD-ROM and DVD drives) rather than bearing responsibility for large messes and lost causes (such as hard disk drives).

Taiwan's financial system has never been particularly open or efficient, but at least the government put priority on not raiding it for either policy or political reasons, an achievement especially impressive in light of the Asian financial crisis. And at least in Taiwan's crucial electronics industry, capital markets have become active and venture capital is second only to that of the United States. Those capital markets helped kill hard disk drives but moved capital to more fitting recipients such as CD-ROMs and semiconductors. In the wake of the Asian financial crisis, the kind of industrial policy that tried to pick winners in Japan and Korea has been severely discredited. Yet the efforts of industries and governments to improve their position in the international division of labor is unlikely to die out. Alternative approaches, such as the mixture of technology support and financial prudence that characterized Taiwan's "ITRI model," are likely to attract increasing attention.

NOTES

¹ For market share by firms based in Taiwan, see the annual *Zixun Gongye Nianjian* (Taipei: Zixun Gongye Cejin Hui)

² In 1999, Via Technologies, a medium-sized chipset maker from Taiwan, purchased the Cyrix microprocessor unit from National Semiconductor and Centaur Technology, the X-86 compatible processor division of Integrated Device Technology, to counter Intel's drive to combine chipset functions with processors, as well as to enter new portable markets such as web surfers. Via had successfully organized the PC133 alliance that defeated Intel's Rambus memory standard. *Electronic Buyers' News*, August 5, 1999; *Far Eastern Economic Review*, September 16, 1999, pp. 54-55; *Semiconductor Business News*, August 5, 1999; Taiwan's Silicon Integrated Systems purchased intellectual property rights for processors and related technology to

complete its “systems-on-a-chip” strategy from Rise Technology, a California semiconductor formed by “haiwai Huaren.” *Electronic Buyers’ News*, October 6, 1999 and October 12, 1999; EETimes, October 13, 1999.

³ Shih-Chang Hung, Chu-Tao Wu and Yee-Yeen Chu, “National Systems, Technology and Industry Development: A Case Study of Taiwan’s Monitor and Hard Disk Drive Industries,” Paper submitted to Workshop on A New Technological Landscape in Asia Pacific, March 11-12, 1999, Taipei, ROC

⁴ David McKendrick, “Sustaining Competitive Advantage in Global Industries: Technological Change and Foreign Assembly in the Hard Disk Drive Industry,” Report 97-06 November, 1997, Information Storage Industry Center, U.C. San Diego

⁵ As noted below, the disadvantages of distance were later ameliorated by improvements in Taiwan’s shipping and customs clearance systems.

⁶ Chalmers Johnson, *MITI and the Japanese Miracle* (Stanford, Cal.: Stanford University Press, 1982); Marie Anchooguy, *Computers, Inc.: Japan's Challenge to IBM* (Cambridge, Mass.: Harvard University Press, 1989)

⁷ Paul R. Krugman, ed., *Strategic Trade Policy and the New International Economics* (Cambridge: MIT Press, 1986), pp. 169-209; Masahiro Okuno-Fujiwara, "Interdependence of Industries, Coordination Failure and Strategic Promotion of an Industry," *Journal of International Economics* 25 (1988), pp. 25-43; Trevor Matthews and John Ravenhill, “Strategic Trade Policy: The Northeast Asian Experience,” in Andrew MacIntyre, ed., *Business and Government in Industrializing Asia* (Ithaca: Cornell University Press, 1994), pp. 29-90

⁸ Alice H. Amsden, *Asia's Next Giant* (New York: Oxford University Press, 1989); Jung-en Woo, *Race to the Swift: State and Finance in Korean Industrialization* (New York: Columbia University Press, 1991)

⁹ Mitchell Bernard and John Ravenhill, "Beyond Product Cycles and Flying Geese: Regionalization, Hierarchy, and the Industrialization of East Asia," *World Politics* 47:2 (January 1995), pp. 171-209

¹⁰ Ironically, lock-in of political and bureaucratic systems can be even worse if the policies are initially successful but later prove unsustainable. Richard Katz, *Japan: The System that Soured—The Rise and Fall of the Japanese Economic Miracle* (Armonk: M.E. Sharpe, 1998)

¹¹ Robert Wade, *Governing the Market* (Princeton: Princeton University Press, 1990); Tun-jen Cheng, "Political Regimes and Development Strategies: South Korea and Taiwan," in Gary Gereffi and Donald L. Wyman, *Manufacturing Miracles* (Princeton: Princeton University Press, 1990), pp. 139-178. Direct mobilization of finance was less aggressive in Japan, but finance continued to play an important indicative role. The Industrial Bank of Japan was especially important. See Kent E. Calder, *Strategic Capitalism: Private Business and Public Purpose in Japanese Industrial Finance* (Princeton: Princeton University Press, 1993)

¹² Otto C. C. Lin, "Science and Technology Policy and its Influence on Economic Development in Taiwan," in Henry S. Rowen, ed., *Behind East Asian Growth: The Political and Social Foundations of Prosperity* (London: Routledge, 1998); Chi-Ming Hou and San Gee, "National Systems Supporting Technical Advance in Industry: The Case of Taiwan," in Richard R. Nelson, ed., *National Innovation Systems* (New York: Oxford University Press, 1993), pp. 384-413

¹³ Gongye Jishu Yanjiuyuan, *Bashierniandu Nian Bao* [1993 Annual Report], pp. 4-5; *Gongye Jishu Yanjiuyuan*, November 1998, p. 5; *Jingji Ribao*, August 4, 1992

¹⁴ Jinn-yuh Hsu, "A Late-Industrial District? Learning Network in the Hsinchu Science-Based Industrial Park, Taiwan," PhD Dissertation, U.C. Berkeley, 1997

¹⁵ Dieter Ernst, "What are the limits to the Korean model? The Korean Electronics Industry Under Pressure," BRIE Research Paper, 1994; Changrok Soh, From Investment to Innovation? The Korean Political Economy and Changes in International Competitiveness (Seoul: Global Research Institute, Korea University, 1997)

¹⁶ *Chanye Jingji* 152 (April 1994), pp. 9-24

¹⁷ David McKendrick, "Sustaining Competitive Advantage in Global Industries: Technological Change and Foreign Assembly in the Hard Disk Drive Industry," Report 97-06 November, 1997, Information Storage Industry Center, U.C. San Diego; Callon reports that an American electronics firm, Magnetic Memories International, began production of hard disks in Singapore in 1979-80. According to Callon, it manufactured full height, 5 1/4" drives with 10-20MB storage capacity, but failed after one year. Scott Callon, "Singapore & Taiwan, PC industry development comparison," Asian Technology Information Program (ATIP), October 9, 1994

¹⁸ Some observers have suggested that American firms may have been more reluctant to transfer cutting edge technology such as designs for hard disk drives to Taiwan than to Singapore. With its raft of small, technologically savvy firms, appropriation of intellectual property rights remained rampant in Taiwan through the 1980s and early 1990s. However, despite occasional conflicts, firms such as IBM, Microsoft and Apple did license key technologies to firms from Taiwan. And by the mid-1990s improved legislation and enforcement persuaded American and Japanese electronics firms to transfer leading edge technologies such as semiconductor and LCD designs to Taiwan. Contemporary accounts attribute the success of Singapore in attracting HDD firms to superior infrastructure and especially an attractive package of tax incentives.

¹⁹ *Taibeishi Yinhang Gongui Huiyuan Danwei Lianhe Banli Chanye Diaocha Baogao* [Taipei City Bank Association Cooperative Industry Survey Reports], 9 April 1986.

²⁰ Zixun Gongye Cejinhui [III], *Zhonghua Minguo 80-nian Zixun Gongye Nianjian* [Yearbook of the Information Industry of the Republic of China] (Taipei: Zixun Gongye Cejinhui, 1991)

²¹ *Zhuoyue Zazhi*, August 1990, p. 111

²² Gregory W. Noble, "From Island Factory to Asian Center: Democracy and Deregulation in Taiwan," Working Paper, Department of International Relations, Research School of Asian and Pacific Studies, Australian National University, October 1997

²³ *Zixun yu Diannao*, May 1986, pp. 11-12

²⁴ Gregory W. Noble, *Collective Action in East Asia: How Ruling Parties Shape Industrial Policy* (Ithaca: Cornell University Press, 1998), chapter six. However, some firms continued to display interest in hard drives. In 1988 and 1992 Tatung contracted with ITRI to transfer prototypes of hard disk drives. Industrial Technology Research Institute, *15th Anniversary* (Hsinchu: ITRI, 1988), p. 41; *Jingji Ribao*, September 25, 1992

²⁵ *Caixun* November 1995, p. 281

²⁶ *Zhuoyue Zazhi*, June 1988, pp. 101-02; *Caixun* November 1995, pp. 280-87

²⁷ *Zhuoyue Zazhi*, June 1988, pp. 101-02; *O&I*, March 1992, pp. 41-48; *Caixun* November 1995, pp. 280-87; III *Nianjian* 1990, p. 217; 1993, p. 207; *Gongshang Shibao* June 30, 1990, November 6, 1993; *Jingji Ribao*, September 25, 1992, December 19, 1992. The purchaser of Taiwan Microscience's equipment was Zentek.

²⁸ *O&I*, March 1992, pp. 41-48; *Caixun* November 1995, pp. 280-87; III *Nianjian* 1992, p. 86; *Gongshang Shibao*, July 7, 1992, July 14, 1993

²⁹ Investors from Taiwan formed a new firm, Myrica, with the assets remaining from Rodime: a design team in Scotland and a factory in Singapore. Like the management of Magtron and other HDD firms in Taiwan, they underestimated the amount of capital required to produce succeeding generations of disks and were unwilling to continue funding. Personal communication, David McKendrick, November 29, 1999.

³⁰ *O&I*, March 1992, pp. 41-48; III *Nianjian* 1992, p. 86; III 1993 *Nianjian* pp. 206-207; *O&I*, November 1991, pp. 188-194; *O&I*, June 1992, pp. 256-261; *Jingji Ribao*, December 19, 1992, July 14, 1993, July 23, 1993

³¹ *O&I*, March 1992, pp. 41-48; III *Nianjian* 1992, p. 86; III 1993 *Nianjian* pp. 206-207; *O&I*, November 1991, pp. 188-194; *O&I*, June 1992, pp. 256-261; *PC World Taiwan* [in Chinese], March 1992, pp. 40-41; *Caixun*, November 1995, pp. 280-287; *Jingji Ribao* February 24, 1991, March 28, 1992

³² *Shichang yu Hangqing* February 3, 1992, pp. 39-41; *Caixun* November 1995, pp. 283-84

³³ *Chanye Jingji* 152 (April 1994), p. 17; *Jingji Ribao*, August 4, 1992, September 28, 1992

³⁴ *O&I*, June 1992, p. 257

³⁵ ITRI also developed servo writers (machines used to put positioning information on metal platters), a major tool used in the production of disc drives. Gongye Jishu Yanjiuyuan [ITRI], *Gongye Jishu Yanjiuyuan 20 Nian Jilu* [A Twenty Year Record of ITRI], (Xinzhu: Gongye Jishu Yanjiuyuan, 1993), pp. 198-199; *Linian Keji Yanjiu Fazhan Zhuan'an Jihua Zhuanli Huibian (xia)* [Special projects for research and development of technology over the years: patents (part II)], (Taipei: Jingjibu Jishuchu, 1994), p. 457; *Gongshang Shibao*, September 7, 1990; *Jingji Ribao*, July 23, 1993

³⁶ *Zhuoyue*, August 1990, p. 112; *Gongshang Shibao* March 23, 1990, and especially October 4, 1990, which features a useful chart summarizing parts producers; *Jingji Ribao* August 31, 1990, January 18, 1991, November 1, 1991; Trace Storage, October 1998, at <www.caita.com.tw/award/97-10.htm>, p. 5 of 27, accessed 2 September 1999

³⁷ *Jingji Ribao*, 6 December 1989; *Gongshang Shibao*, January 19, 1990

³⁸ *Gongshang Shibao*, October 4, 1990

³⁹ *Caixun*, November 1995, pp. 280-87; *Jingji Ribao*, May 17, 1994; *Gongshang Shibao*, August 20, 1999; Mototech press announcement, 1 June, 1999; <<http://www.mototech.com.tw/>> accessed September 3, 1999

⁴⁰ *Caixun* November 1995, pp. 284-85; *Gongshang Shibao* August 27, 1990, September 6, 1990, October 21, 1991; III *Nianjian* 1992, p. 87

⁴¹ *Jingji Ribao* September 4, 1990, January 18, 1991

⁴² *Zhuoyue Zazhi*, August 1990, p. 112; III, 1992 *Nianjian* p. 87

⁴³ *Jingji Ribao* September 4, 1990, January 18, 1991

⁴⁴ *Caixun November*, 1995, pp. 280-287; Trace Storage, October 1998, at <www.caita.com.tw/award/97-10.htm> accessed 2 September 1999; *Gongshang Shibao*, February 15, 1990, February 22, 1990, March 23, 1990, June 17, 1994, September 11, 1996, April 24, 1997; *Jingji Ribao*, February 23, 1990, August 27, 1992, August 29, 1996; personal communication from David McKendrick, November 29, 1999

⁴⁵ *Gongshang Shibao* February 10, 1999; *Xin Bao* December 24, 1998, December 28, 1999; *Chen Bao*, 21 July, 1999

⁴⁶ *Shichang yu Hangqing Zhoukan*, January 27, 1992, pp. 31-33, February 3, 1992, pp. 39-41; *O&I*, March 1992, pp. 48. See also *PC World Taiwan* [in Chinese], March

1992, pp. 40-41; *O&I* November 1991, pp. 188-94; *Gongshang Shibao* January 20, 1992

⁴⁷ *Shichang yu Hangqing Zhoukan* February 24, 1991, p. 33; *O&I* March 1992, p. 43

⁴⁸ *Gongshang Shibao* August 15, 1992, October 1, 1992, October 30, 1993; *Jingji Ribao* August 4, 1992, August 6, 1992, September 15, 1992, September 25, 1992; on the skepticism of local computer firms toward Taiwan's hard disk industry, see *Jingji Ribao* November 11, 1991, February 24, 1992, August 4, 1992, September 15, 1992; *O&I*, November 1991, pp. 184, 187

⁴⁹ *Jingji Ribao*, July 23, 1993

⁵⁰ *Jingji Ribao*, March 7, 1994, June 7, 1994

⁵¹ Noble, *Collective Action in East Asia*, pp. 153, 84-86

⁵² *Jingji Ribao* October 12, 1994, October 19, 1994, October 27, 1994; *Zhongguo Shibao*, October 12, 1994; *Caixun* November 1995, p. 284

⁵³ *Ziyou Shibao* May 2, 1995, May 3, 1995; *Jingji Ribao* May 12, 1995, May 14, 1997, July 2, 1998; <http://www.hfs.com.tw/unmarket/un16.htm> accessed November 22, 1999.

⁵⁴ *Jingji Ribao*, November 20, 1996, January 4, 1997, January 20, 1997

⁵⁵ Noble, "From Island Factory to Asian Center"; *Jingji Ribao*, September 6, 1997; *Gongshang Shibao*, February 21, 1999

⁵⁶ *Chanye Jingji* April 1994, p. 22, citing data from Disk/Trend and MIC.

⁵⁷ For a chronological list of CD standards and other background on the technological base and market applications of CD-based products, see Xin Dianzi Keji Zazhi, 1999 *Dianzi Gongye Shichang Nianjian* [1999 Yearbook of the Electronics Industry Market] (Taipei: Taibeishi Dianzi Lingjian Shangye Tongye Gonghui and Disanbo Zixun, 1999), pp. 217-228

⁵⁸ In 1985 Several overseas Chinese engineers received government approval to set up a plant in Taiwan to produce optical disks, but as far can be determined nothing ever came of the plan. *Taiwan Electronics* 64 (January 1986), pp. 36-37

⁵⁹ III *Yearbook* 1992, p. 87. A photo of the crude prototype, then known as WORM (write once, read many times) appears in ITRI *Annual Report 1991*, pp. 20-21. See also Jingjibu Jishuchu, *Chanye Jishu Baipishu* 1994, pp. 62-63 and the English-language version of III *Yearbook* 1991, p. 68.

⁶⁰ *Gongye Jishu Yanjiu Yuan 20 Nian Jiyao* [20 Years of ITRI: A Record of Important Events] (Xinzhu: ITRI, 1993), pp. 198-201.

⁶¹ Jingjibu Jishuchu, *Chanye Jishu Baipishu* 1995, pp. 112-115, 376-385; Jingjibu Jishuchu, *Chanye Jishu Baipishu* 1998, pp. 156-160, 436-459; ITRI Guangdian Gongye Yanjiusuo pamphlet, 1996 and interviews with Dr. Kuei Ching-ping and Chang Shun-Hsien, *Guangdiansuo*, June 22, 1999; ITRI, *Annual Report 1992*, p. 22 *Chanye Jingji* 211 (March 1999), pp. 56-59

⁶² *Guangdiansuo* pamphlet, 1996, *Chanye Jingji* 211 (March 1999), p. 57 and interviews with Dr. Kuei Ching-ping and Chang Shun-Hsien, *Guangdiansuo*, June 22, 1999. In a much more limited form, the Dutch electronics pioneer Philips, Taiwan's largest foreign investor and the principle inventor of the compact disk, performed the same function. Since Philips, unlike the American consumer electronics companies, competed directly with the Japanese in consumer electronics, it depended heavily on Taiwan's lost-cost production structure and Asian presence to complement its own formidable European R&D capacity. However, unlike the comprehensive support provided by ITRI, Philips activities were naturally limited to its own product range. Nor was Philips in the business of providing engineering consulting or transfer of crucial systems integration technology to potential competitors.

⁶³ Interviews with Dr. Kuei Ching-ping and Chang Shun-Hsien, Guangdiansuo, June 22, 1999. For earlier evidence from an industrial economist, see Chi Schive, *The Foreign Factor: The Multinational Corporation's Contribution to the Economic Modernization of the Republic of China* (Stanford, Calif. : Hoover Institution Press, 1990)

⁶⁴ Guangdiansuo ITIS Jihua, “1998 Nian Woguo Guangdian Chanye Xiankuang yu Zhanwang” [Taiwan’s Opto-Electronics Industry in 1998: Current Situation and Future Prospects], *Dianzi Chanye Touxu*, December 1998, p. 5.

⁶⁵ *Chanye Jingji* 164 (April 1995), pp. 89-92; *Chanye Jingji* 211 (March 1999), pp. 56-59; *Chanye Jingji* 212 (April 1999), pp. 87-94. First quarter 1999 unit prices from *Gongshang Shibao*, July 10, 1999

⁶⁶ *Chanye Jingji* 211 (March 1999), p. 59; *Gongshang Shibao* July 10, 1999, July 21, 1999, August 17, 1999 and August 26, 1999; *Jingji Ribao* July 12, 1999 and September 1, 1999.

⁶⁷ *Gongshang Shibao*, July 16, 1999 (CD-R Guangdiepian Zhuankan); Guangdiansuo ITIS Jihua, “1998 Nian Woguo Guangdian Chanye Xiankuang yu Zhanwang” [Taiwan’s Opto-Electronics Industry in 1998: Current Situation and Future Prospects], *Dianzi Chanye Touxu*, December 1998; *Business Week*, August 9, 1999, p. 28; *Far Eastern Economic Review* July 15, 1999, p. 48.

⁶⁸ *Investext Reports*, May 12, 1999; *Gongshang Shibao*, July 16, 1999 (CD-R Guangdiepian Zhuankan)

⁶⁹ *Gongshang Shibao*, July 16, 1999 (CD-R Guangdiepian Zhuankan)

⁷⁰ Author interview with S.C. Hong (Hong Xingcheng), President, Hotung [Hetong] Group, June 24, 1999.

⁷¹ *Gongshang Shibao*, July 16, 1999 (CD-R Guangdiepian Zhuankan); Milford B.

Green, *Venture Capital: International Comparisons* (London: Routledge, 1991).

Despite recent progress in other Asian countries, Taiwan continues to maintain a clear lead. See *Far Eastern Economic Review*, September 10, 1998;

⁷² *Gongshang Shibao* June 15, 1999; Market Intelligence Center, “Developments in the Global DVD-ROM Industry,” *Asia IT Report*, April 1999

⁷³ ITRI Guangdiansuo, *Guangdian Chengguo Jikan*, May 1999, pp. 14-16. ITRI, *Bashiqi Niandu Nianbao*, pp. 12-13. All members of DVD forum can establish B-Class laboratories to test and certify that products comply with DVD format, but B-Class laboratories can only be established with guidance from A-Class laboratories such as that erected in Hsinchu.

⁷⁴ ITRI Guangdiansuo, *Guangdian Chengguo Jikan*, May 1999. When the author visited the Opto-Electronics and Systems Laboratories in June 1999, the lobby was crowded with industry representatives gathering to attend yet another meeting on DVDs.

⁷⁵ ITRI, *Bashiqi Niandu Nianbao*, pp. 12-13; ITRI Guangdiansuo, *Guangdian Chengguo Jikan*, May 1999, pp. 14-16

⁷⁶ *Gongshang Shibao*, August 26, 1999; *Zhongguo Shibao*, October 22, 1999

⁷⁷ These projects were of average size. Among the larger projects, the grant for research on lithium batteries was about eight times larger, and that for CDAM personal telecommunications about ten times larger. As of FY 1998, MOEA funding for four and five year plans for CD and DVD related “special project” funding totaled NTD \$640,642,260 [around USD \$18,300,000 at 35 NTD/USD] out of a total NTD \$5,661,892,931,000 [about USD \$161 million] for electronics and information and

NTD \$13,698,504,271 for all MOEA special projects. MOEA Jishuchu, *Chanye Jishu Baipishu 1998*, pp. 156-160, 436-438, 447-449, 459.

⁷⁸ *Gongshang Shibao*, September 1, 1999

⁷⁹ Capital and engineering talent that might have been squandered in the hard disk drive business also moved to less directly related components of the electronics sector, such as Taiwan's remarkably successful specialized semiconductor fabrication facilities.

⁸⁰ Gregory W. Noble and John Ravenhill, "The Good, the Bad and the Ugly? Korea, Taiwan and the Asian Financial Crisis," Noble and Ravenhill, eds., *The Asian Financial Crisis and the Structure of Global Finance* (Cambridge: Cambridge University Press, 2000)

⁸¹ Author interview with S.C. Hong (Hong Xingcheng), President, Hotung [Hetong] Group, June 24, 1999.

⁸² Cheng, "Political Regimes and Development Strategies" and Yun-han Chu, *Crafting Democracy in Taiwan* (Taipei: National Center for Policy Research, 1992), chapter five