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Advanced Displays in Korea and Taiwan

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Introduction

The purpose of this paper is to present results of field research on firm strategies and government policies in Korea and Taiwan with respect to a global high-technology industry: advanced displays. The authors of this article are part of a larger team of researchers funded by the Alfred P. Sloan Foundation to study the global advanced display industry.¹ This industry was selected for study because of its relationship to other high technology industries, particularly the semiconductor and computer industries. In the larger study, field research was also conducted in four other countries: the United States, France, the Netherlands, and Japan. The six countries taken together account for over 95% of worldwide production of advanced displays.

The semiconductor and, to a lesser extent, the advanced display industries have been the focus of attempts on the part of the governments of major industrialized nations to catch up or stay ahead for both economic and military purposes. Both industries involve very large and high-risk capital investments in high-volume production that is subject to dynamic economies of scale or learning-curve economies. Therefore, they represent temptations for governments to engage in strategic trade and investment policies.² Both industries provide high value-added and product-differentiating components for the much larger electronics industry complex which is a generator of wealth,

exports, and a substantial number of jobs. However, in no country does government intervention appear to have been decisive in stimulating a domestic display industry -- despite millions of dollars spent for this purpose. In particular, the United States appears to have spent the most in support of the display industry with the least to show for it to date.

The focus here is on the strategies pursued by Korean and Taiwanese firms and policymakers to enhance domestic participation in the advanced display market. We selected these two countries because they are often singled out among the newly industrializing countries (NICs) as exemplars of successful industrial development. Both countries had already successfully entered the world market for dynamic random access memories (DRAMs) and both had recently entered or were on the verge of entering the market for advanced displays at the time we began our field research.

We will assess the case study evidence using two different perspectives: those of Asia skepticism and globalization.

The central claim of the Asia skeptics is that the economic wealth of the NICs is unlikely to reach that of the more advanced countries. This has been argued in at least two different ways.

Economists have used aggregate data to support the claim that NIC growth has been driven primarily by mobilization of resources (which cannot be increased without limit), rather than by improvements in technology or productive efficiency (which -- theoretically -- can).³ This argument was given particularly high visibility in an article published by Paul Krugman (1994), in which he argued that the NICs would face persistent "technological gaps" vis-à-vis wealthier countries.⁴

Political scientists have arrived at similar conclusions using a different approach. Mitchell Bernard and John Ravenhill (1995) revisited the earlier argument of Bruce Cumings (1984) that the East Asian countries followed a strategy of "flying geese"⁵ in which technology flowed from the leader (Japan) to its closest followers and then to their followers, with the process ultimately leading to industrial convergence. Bernard and Ravenhill argued that homogenization would fail to occur because Japanese dominance of the regional production structure stifled technology flows and maintained the dependency of the followers.

An alternative perspective incorporates some of the same tools but in a broader framework, that of "globalization". East Asia is no longer simply a Japanese preserve. For example, Michael Borrus (1994) describes how American electronics firms have worked with producers in Asia to develop specializations as part of a regional "architecture of supply".

Borrus and John Zysman (1997) offer a more complete account of this process. The defining characteristics of globalization include Cross-National Production Networks and "Wintelism", the ability to acquire market power (and hence wealth) within a network through control of product design, components, brand name, or some other non-imitable asset.⁶ Thus, any actor in the network can

potentially gain power by choosing the right technological strategy. The hierarchy no longer need be seen as frozen in place.

Here we present case studies based on interviews at Korean and Taiwanese firms and government agencies involved in the global advanced display industry. Following the case studies, we begin by comparing the political economy of the flat panel display industries in Korea and Taiwan. We find that in both countries, the results of government actions during the post-war period have effectively narrowed the margin for policy interventions in each economy, but in different ways. We then turn to firm-level analysis to evaluate the willingness and ability of the firms in our study to close the technological gap with Japan in flat panel displays, and how differences across firms determine their strength in their respective networks. In general, Korean firms appear to be more willing to compete aggressively with the Japanese, whereas the Taiwanese seem to favor a safer approach which restricts them to a supporting role in cross-national networks. In a concluding section, we consider what the Korean and Taiwanese cases tell us about the display industry in the United States.

The Global Advanced Display Industry

Advanced displays are visual interfaces for advanced electronic equipment.⁷ They are used in computers, televisions, industrial machinery, medical diagnostic equipment, automotive applications, military systems, and a number of other products. There are a wide variety of display technologies that are capable of handling the varying degree of picture detail, color, brightness, and other characteristics required to present the graphics generated by advanced electronics equipment. One important distinction is between displays that use cathode ray tubes (CRTs), a relatively old but still-evolving technology, and flat panel displays, a set of technologies that has existed for decades but is only now being developed on a large scale.

Roughly 120 million TVs are sold annually throughout the world, along with about 60 million desktop computers. Over 95% of televisions and desktop computer monitors still employ CRT technology. But sales of portable ("notebook") computers are increasing faster than those of desktops, which in turn are increasing faster than those of television sets. CRTs, because of their bulk and their high power consumption, are not well-suited to portable applications, so flat panel displays are used instead. Roughly 11 million notebook computers were sold in 1996, and every one of these computers had a flat panel display. According to a recent forecast, 31.3 million flat panel displays will have been sold in 1997 (including smaller displays for handheld TVs, personal digital assistants, handheld games, and other portable electronic products) with a total value of \$10.2 billion.⁸

The leading flat panel display technologies are liquid crystal displays (LCDs), vacuum fluorescent displays (VFDs), plasma display panels (PDPs), and electroluminescent (EL) displays. A potentially important new technology is the field emission display (FED). Currently over 80% of all flat panel display revenue is accounted for by LCDs, primarily because of their emergence in the early

1990s as the industry standard for portable computers. LCDs are capable of displaying color images at resolution levels, brightness, response rates, power consumption, and market prices acceptable to consumers. Other displays are lacking in at least one of these areas.

In the LCD category, there are two main types currently on the market: the super-twisted-nematic LCD (STN-LCD) and the thin-film-transistor LCD (TFT-LCD). The STN-LCD has lower contrast, a worse viewing angle, and a slower response time than the TFT-LCD, but is less expensive to produce. The production process for TFT-LCD is considerably more complicated than that for STN-LCD. For this reason, the price of a notebook computer with a STN-LCD is at least a few hundred dollars lower than an equivalent machine with a TFT-LCD. Despite the price premium, sales of TFT-LCD-equipped notebooks have been quite strong, and TFT-LCD screens accounted for more than half of all notebook displays in 1996.

As firms become more experienced with the production of TFT-LCDs, the gap in the price between STN- and TFT-LCDs has been declining, as has the gap in prices between monitor-sized CRTs and equivalent LCDs. Thus, even though LCDs are currently too expensive to be used for television and desktop computer monitors, that may not be true in the future. Stanford Resources projects that the share of flat panel displays in the market for all display types will increase from its 1997 level of 27% to 43% in 2003.⁹

Over 95% of global TFT-LCD production prior to 1995 was in Japan. Japanese producers of flat panel displays are continuing to make new investments in TFT-LCDs.

Japanese firms were willing to transfer STN-LCD technology to firms in other countries but preferred not to do so for TFT-LCD production technology. Thus, a decision on the part of a Taiwanese or Korean firm to invest in TFT-LCDs was a good test of the willingness of the firm to compete at the technological frontier with major Japanese producers.

TFT-LCD Manufacturing

TFT-LCD manufacturing is both challenging and risky. The current generation of TFT-LCD fabrication plants (generation 3 -- see Table 1) requires an investment of about \$500 million to begin production. For new entrants, attaining a satisfactory yield of usable displays can pose a major challenge because a few defects among the many thousands of transistors which are deposited simultaneously on the glass can render a display unusable.

The screen size of flat panel displays for notebook computers has grown much faster than was previously expected, primarily because plants using larger glass sizes (and optimized for larger displays) entered their volume production phase faster than was generally anticipated. It was only in 1992 that the first notebook-size screen, measuring 8.4" diagonally, became available in high volumes. These displays were displaced with slightly larger 9.5" displays, then 10.4" in rapid succession. By 1995, 11.3" displays had caught on, but before they could gain a dominant share of the market in 1996, they were superseded by 12.1" displays,

which have become the dominant format for notebook computer screens. A future shift to 13.3" displays is possible as "generation 3.5" factories become active. Larger sizes may become commonplace as LCDs appear in the desktop monitor market.

These shifts frequently caught firms unprepared. Because of the long lead-time involved, investment plans could not easily be changed to compete with firms that had successfully adopted a more advanced generation of technology. As we will see below, investments -- particularly in Taiwan -- were sometimes postponed while companies waited to see how the market would evolve. In one case, a major Korean producer, Samsung, converted a plant designed to produce 10.4" displays to the production of 12.1" while a dedicated 12.1" plant was under construction. The loss in efficiency was apparently more than offset by the higher margins commanded by the larger display sizes.

Table 1. Generations of TFT-LCD and STN-LCD Manufacturing Equipment

Generation	Size of Motherglass	Optimized for Display Size (qty.)	Earliest Adoption (adopter)
1	300mm x 400mm	8.4-inch (4)	1991 (Sharp)
2	350mm x 450mm	10.4-inch (4)	1994 (Sharp/Hosiden)
3	550mm x 650mm	12.1-inch (6)	1996 (DTI)
3.5	600mm x 720mm	14.1-inch (6)	1997/8 (LG, Sharp)
3.5+	650mm x 830mm	15.0-inch (6)	1997/8 (Hitachi)

Sources: Business press and interview materials.

Because of learning economies in TFT-LCD production, the price for any given size of display will decline over time, just as it did for integrated circuits. Integrated circuits are always shrinking in size in order to achieve greater yields per silicon wafer, and new investments are needed for equipment that can produce at finer tolerances. Similarly, as TFT-LCDs grow larger in size, new

investments are needed for equipment capable of handling larger "motherglass" (the large sheet of glass, also known as a substrate) on which multiple display panels are processed.¹⁰

The production technology for TFT-LCDs is quite complex, bearing many similarities to that for integrated circuits. Both TFT-LCD and IC production require clean rooms, photolithography, chemical and physical vapor deposition, and advanced testing. An error at any of the process steps may produce a faulty device. TFT-LCD production is highly capital-intensive, but extensive training is required for clean room production workers, and even after a factory is producing at full capacity a large team of production engineers must be on hand to diagnose and fix production problems.

TFT-LCD production relies on certain key inputs. In particular, color filters, driver chips, and backlights each account for between 5 and 15% of the marginal cost of a display. They can be purchased from outside suppliers, but, when periodic shortages arise, factory output may need to be curtailed. As we will see below, some of the firms in our case studies have taken steps to ensure reliable supplies by initiating internal production.

The TFT-LCD industry has settled into a pattern similar to that for commoditized integrated circuits like memory chips -- large and increasing capital requirements combined with uncertainties about the time required to ramp up production and uncertainties about the growth in demand lead to difficulties in correctly timing investments, causing alternating periods of glut and shortage.¹¹ When there is a shortage, prices are high and firms not currently participating in the market are tempted to enter. This may lead to overinvestment, followed eventually by overproduction, oversupply, and price erosion. For example, competitive investment behavior by Korean producers of TFT-LCDs in the 1995-96 period eroded the formerly rich profit margins of Japanese firms, especially for smaller screen sizes, and discouraged new investments by firms in Taiwan and the United States. When demand for 12.1" displays picked up again in 1996-97, Japanese and Korean firms expanded capacity and firms in Taiwan and the United States began to reconsider investments in display production.

One of the important things we learned from our field research was that the market for displays is relatively insensitive to the location of display production. The assemblers of notebook computers need access to the highest-quality and lowest-priced displays with a given set of performance characteristics regardless of where they are produced. All that is required, usually, is for the display producer to locate a warehouse close to the assembly plant and keep it stocked for just-in-time delivery of displays.

As we turn to the case studies, we will see that the cyclical nature of the display market had different effects on different firms. In Korea, the two leading firms took a long-range view and invested heavily in TFT-LCD production. In Taiwan, where firms act more on short-run considerations, the periodic declines in the market have been sufficient to delay production plans.

The Advanced Display Industry in Korea

The main actors in the Korean display industry are the big-three *chaebol* electronics firms -- Samsung, Hyundai, and LG (formerly called Lucky Goldstar) -- and the major governmental ministries charged with supporting technological innovation -- the Ministry of Trade, Industry, and Energy (MoTIE) and the Ministry of Science and Technology (MoST).¹² In Korea, the *chaebol* -- large, diversified industrial conglomerates that grew to their current size in Korea's heavy industry expansion period -- initially acted independently of the government to make investments in TFT-LCD production. Samsung, LG, and Hyundai each established TFT-LCD production facilities by purchasing the necessary equipment and engineering advice from Japan. Because of a perceived need to reduce dependence on Japanese production tools, the Korean government decided to involve itself and created a new organization, called EDIRAK (the Electronic Display Industry Research Association of Korea), to develop local equipment supply. Government impact on the industry is still minimal, and the main driver for Korean involvement in the TFT-LCD market continues to be private firms.

The Chaebol Decide to Invest in TFT-LCD Production

Of the three *chaebol* investing in TFT-LCDs, Samsung was the earliest in setting up high-volume production. Samsung was less cautious than either LG or Hyundai in investing in current generation production equipment. Finally, Samsung adopted a forward-pricing strategy that allowed it to win market share away from the larger Japanese producers as early as late 1995. While LG and Hyundai were less aggressive than Samsung, both proceeded in a steady manner to establish TFT-LCD production facilities. By 1997, both firms were positioned to become full competitors with Samsung and the Japanese producers. Each of the three firms had invested over \$800 million in TFT-LCD plants by the late 1990s. When the demand for 12.1" displays picked up in 1996-97, they began to reap the benefits of their decisions. We will argue in the concluding sections of this paper that this was possible for them because of the long time-horizons of *chaebol* managers, and that this long-range outlook is to some extent an artifact of the way the Korean financial system is regulated.

Samsung

Samsung Display Devices (SDD -- with 1995 revenues of \$2.3 billion) is an affiliate of Samsung Electronics (\$19.4 billion in revenues in 1995), and both are members of the Samsung Group (\$25 billion in revenues in 1995). In 1984, SDD created a TFT-LCD study group to conduct laboratory research. Samsung subsequently licensed technology from Optical Imaging Systems, one of America's only producers of TFT-LCDs, and also hired researchers away from Japanese labs as another means of acquiring needed technology.¹³ In January 1991, the TFT-LCD business was transferred to the semiconductor group of Samsung Electronics, while SDD retained the STN-LCD business. Samsung Electronics completed a pilot plant using 300mm x 300mm (sub-first generation) motherglass in Kiheung in 1991. The following year it developed a prototype 10.4" VGA display for two-at-a-time ("2-up") production on 300mm x

400mm motherglass and began processing 2,400 of these substrates per month on a new pilot line in September 1993, selling the displays primarily to external customers.

The decision to move to mass production had high level support from both Kwangho Kim, Vice Chairman and President of Samsung Electronics, and Kun-Hee Lee, Chairman of Samsung Group and son of the founder. During our interviews at Samsung, we learned that at least one motivation for Samsung's investment in TFT-LCD production was their reaction to a statement by a Japanese group to the effect that the Koreans would never be able to successfully challenge Japanese production in TFT-LCDs. There was reportedly a similar motivation behind Samsung's investments in DRAM production. But beyond such competitive motives lay Samsung's interest in assuring itself access to state-of-the-art electronic components for a wide variety of electronic products.

Samsung built a second-generation, high-volume production facility ("line 1") at Kiheung using 370mm x 470mm motherglass late in 1993, which began full-scale production in February 1995. By July, the line was processing 20,000 substrates per month, each of which contained four 10.4" VGA displays. At full capacity, therefore, the line could produce about a million displays per year.

In 1995, Samsung was able to enter into a cross-licensing agreement with the Japanese firm Fujitsu, a fellow late-entrant into the TFT-LCD market. Fujitsu provided Samsung with wide-viewing-angle technology in exchange for Samsung's high-aperture-ratio technology. Wider viewing angles are important for overcoming one of the limitations of LCDs compared with CRTs. A high aperture ratio means more light from the backlight reaches the viewing surface, making the display easier to read and reducing power consumption.

In April 1996, Samsung invested in a new facility in Kiheung for the production of 12.1" SVGA displays on 550mm x 660mm motherglass (third generation) with an annual production capacity of 1.5 million displays per year. The cost to Samsung to set up this plant was between \$600 and \$800 million. Most of the production equipment is Japanese. In 1998, Samsung expects to achieve an 80% yield processing 25,000 substrates per month with six 12.1" panels on each piece of 550mm x 660mm motherglass on line 2. Samsung converted line 1 to the production of 12.1" displays in 1996 to meet market demand even though this meant a major decline in output and yield, making them more than usually anxious to get to full production at line 2.

The next TFT-LCD production line (line 3) for Samsung will be built at Cheonan.¹⁴ It will be a generation 3.5 plant to produce 13.3" XGA and 17.0" SXGA displays on 600mm x 720mm motherglass. Construction was begun in November 1996. The company expects the plant, with a total potential capacity of 30,000 substrates per month, to be completed in the second quarter of 1998.¹⁵ The total investment over two years will be about \$900 million.

Although it is largely dependent on foreign sources for TFT-LCD production equipment, Samsung can meet many of its needs for intermediate inputs

internally. In late 1996, Samsung Corning, a joint venture between Samsung and Corning Glass, began processing the special glass used in TFT-LCDs. Samsung Aerospace was bidding for the right to supply lithography equipment for TFT-LCD production. And Samsung Display Devices will be manufacturing color filters for a large proportion of Samsung TFT-LCDs by the end of 1998.

Samsung also has strong prospects for downstream integration. In 1996, it purchased AST Research, an ailing U.S. manufacturer of desktop and notebook PCs. Samsung was already the largest seller of computers in Korea and one of the top ten sellers in Asia. In June 1997, it announced a 14-inch XGA TFT-LCD desktop monitor, although it doesn't anticipate a major market for such products until 1999.¹⁶

In April 1997, Samsung told its investors that it had recorded a profit on an annual basis at its TFT-LCD manufacturing unit for the first time.¹⁷ Thus, Samsung Electronics, which had developed its high-volume electronics manufacturing capabilities in vertically integrated production of consumer electronic equipment and semiconductors over a quarter century, was able to redeploy these resources relatively rapidly to compete successfully in the demanding TFT-LCD market.

LG

LG Electronics, with 1995 revenues of nearly \$8.5 billion, is part of the LG Business Group. The electronics affiliates of the LG Group are about half the size and considerably less vertically integrated than those of the Samsung Group. TFT-LCD research began at LG Electronics in 1987, and by 1989 they demonstrated their first working device. In 1990, an R&D center was established at Anyang. That pilot line still processes about 12,000 substrates a year with about 250 employees. It currently produces 10.4" SVGA and 12.1" SVGA displays.

In 1993, LG broke ground for a major production facility ("line 1") at Kumi, one of Korea's "science parks." By 1994, the new line was processing 10,000 sheets of 370mm x 470mm glass (second generation) per month, with a maximum output of 40,000 per month. By June 1996, line 1 was producing 1.8 million 10.4" display-equivalents per year with about 1,400 workers after a total investment of around \$600 million.

LG's decision to invest in TFT-LCDs was not based solely on financial considerations because the uncertainty about the eventual size of the market was too great. The final decision was made by then-president Hun-Jo Lee on the basis of "visionary thinking." President Lee saw LG developing a core competence in personal portable products, which use LCDs as a core component. Also, LG sought to reduce its reliance on CRT-based televisions and monitors. Another motivation for TFT-LCD production was to reduce dependence on Japanese component sources. In the past, shortages of specialized motors and chips had delayed LG's production of advanced VCRs. LG was similarly dependent on Sharp for the displays used in its portable TVs.

The top management in the LG Group strongly supported the TFT-LCD effort. Whereas the TFT-LCD division was allowed to request personnel to be transferred from anywhere in the company, transfers out of the division required President Lee's written approval. Support remains strong. When the company was reorganized in 1996, collapsing its structure from ten strategic business units (SBUs) to four, LCDs were kept separate as one of the four.¹⁸ In 1996, equipment was installed for line 2 at Kumi using third-generation technology. Line 2 should begin operation in late 1997, and could eventually process up to 40,000 substrates per month, the equivalent of over two million 12.1" displays per year. They planned the facility originally for 550mm x 650mm motherglass but later extended this to 580mm x 670mm to accommodate the production of larger displays. Line 2 will integrate filter manufacturing with TFT fabrication (driven by a shortage of TFT-LCD filters currently imported from Japan). Another group member, LG Semicon, is the main source for driver ICs.¹⁹ Other member firms have developed materials, such as color resist, and on backlights.

In 1994, LG was able to enter a \$30 million joint venture with Alps Electric, a Japanese components firm, to develop "ultra clean" manufacturing technology for TFT-LCDs. The research was undertaken at Alps Central Laboratory in Japan. Alps started this research in 1988 in cooperation with a local university but had run into financial trouble. After other Japanese firms declined appeals to jointly fund the effort, Alps turned to LG. The technology would be employed for the first time on LG's line 2.²⁰

LG also undertook a joint development project (including an equity investment) with Photon Dynamics, an American producer of display test equipment. Photon Dynamics was one of the first companies to make tools for testing the individual pixels of a TFT-LCD at intermediate stages of the manufacturing process. The cooperation was crucial to LG's strategy of pursuing zero defects (displays are sold with as many as five defective pixels), which in turn helped it earn a five-year contract to supply \$1 billion worth of 12.1" and larger displays to Compaq -- a significant achievement for a company with barely one year of volume production behind it.²¹

TFT-LCD production helped LG to improve its position in downstream markets. In May 1996, LG established a strategic alliance with Digital Equipment Corporation (DEC) of the United States to supply 11.3" and 12.1" displays for jointly developed notebooks that would be marketed by DEC.²² In August 1997, the new designs were finished and LG began to supply fully assembled notebooks to DEC at a rate of 10,000 units per month. This arrangement replaced an earlier one that DEC had with Citizen Watch Company of Japan.²³

The next LCD investment in the LG Group will be made by LG Semicon, which seeks to diversify out of DRAMs. In March 1997, the firm announced a new investment program of \$1 billion for a new line at Kumi to produce 13.3" and 15.0" displays. The announcement said that the new line, which may use

motherglass as large as 890mm x 670mm, would be up and running sometime in 1998 at a maximum rate of two million displays per year.[24](#)

Hyundai

Hyundai Electronics Industries (with 1995 revenues of \$5 billion) is the electronics arm of the Hyundai Group (1995 revenues of \$75 billion). In 1992, Hyundai began working with a small American TFT-LCD firm called Alphasil -- and its co-founder Scott Holmberg -- which had been abandoned by a previous corporate sponsor, Honeywell. Hyundai was impressed with the progress Holmberg had made toward establishing a TFT-LCD pilot production line with very little capital, and Chairman Mong-Hun Chung of Hyundai Electronics sent a team of engineers to California to work with Holmberg on what was to become Hyundai's line 1, producing specialized displays for aircraft and military use. A new firm, ImageQuest, was established as a subsidiary of Hyundai with Holmberg in charge. Hyundai made an initial investment of \$40 million to complete the pilot line. The ImageQuest investment was part of a broader effort to internationalize Hyundai's activities. Hyundai learned about TFT-LCD technology through ImageQuest but ultimately decided that the primarily U.S. production equipment on ImageQuest's pilot line was appropriate for laboratories or pilot lines, but not for high-volume production. ImageQuest was closed in November 1997 because it had "fulfilled its business mission," according to a company spokesperson.[25](#)

In late 1993, Hyundai broke ground at Ichon for a high-volume production facility capable of 4-up production of 10.4" displays on 370mm x 470mm motherglass (second generation). All of the equipment for line 2 was Japanese. They used Nikon steppers, for example, because they needed an uptime of about 90% to justify the investment in LCDs, and only the Japanese vendors could guarantee this. In general, Hyundai engineers had not had good experiences working with U.S. suppliers of semiconductor production equipment. The main exceptions to this were the chemical vapor deposition tools Hyundai purchased from Applied Komatsu (AKT, a U.S.-Japanese joint venture) and Watkins Johnson (no longer producing display equipment). High volume production did not begin until mid-1996.[26](#) Line 2 was originally planned to process 20,000 substrates per month, but actually operated at a rate of around 12,000 per month.

Plans for a second Ichon plant were announced in June 1996, and ground was broken in March 1997. The plant was to feature a third-generation production line with 550mm x 650mm motherglass for 6-up production of 12.1" displays at a rate of 35,000 substrates per month. But market demand shifted so rapidly that Hyundai added a 5,000 substrate per month line in the existing plant to produce 12.1" displays and upgraded the line under construction to handle 600mm x 720mm motherglass (generation 3.5, comparable to Samsung's plans for the Cheonan facility) for 6-up production of 13.3" displays.[27](#) The new plant -- to be completed in 1998 -- is projected to cost nearly \$600 million, a down payment

on the five-year, \$1.8 billion investment plan for TFT-LCDs that Hyundai announced in June 1997.

Despite its latecomer status, Hyundai received a vote of confidence from Toshiba in late 1996, when the latter signed a contract to purchase 10,000 12.1" displays per month from Hyundai. Although Toshiba has access to displays from Display Technology Inc., its joint production venture in Japan with IBM, it preferred to sell some of those displays to other companies in order to gain knowledge about market trends. Toshiba will be transferring its designs (via mask sets) to Hyundai, which had previously licensed Toshiba technology.²⁸

As with Samsung and LG, the decisions to invest in TFT-LCD production at Hyundai Electronics were made at the highest level. Once again, a key goal was to internalize a core component for multimedia systems. But Hyundai's managers took a more cautious approach to entering the TFT-LCD business than their opposite numbers in Samsung and LG. A possible explanation is that Hyundai lacked the added motivation of seeking a hedge against the possible obsolescence of CRTs, which SDD and LG produce but Hyundai does not.

The Role of Government Policy in the Korean Display Industry

The Korean government did not get directly involved in supporting the entry of Korean firms in the TFT-LCD market until rather late in the game. Some government funds facilitated entry by, for example, subsidizing the facilities in science parks like Kumi or helping to fund training programs for LCD engineers. In 1991, the Ministry of Trade, Industry and Energy (MoTIE) launched a \$6.4 million program for the development of notebook display modules leading to the creation of a 10" module in 1994. All four of Korea's major electronics firms (Samsung, Hyundai, Daewoo, and LG) participated. The government then tried unsuccessfully to get the four firms to invest in a joint venture for display production. The most the four firms were willing to do jointly, however, was to engage in cross-licensing of technologies. On the whole, it was the *chaebol* themselves who took the risks and made the key investments with little direct guidance or intervention from the government.

By the mid 1990s, the Korean government began to think that the firms' overwhelming reliance on Japanese manufacturing equipment was not necessarily in the long-term interest of the industry, and that government intervention was needed to reduce dependence on Japan. Two major funding efforts addressed this issue: (1) the G-7 HAN Project, and (2) a new program proposed in October 1996 by the Minister of Trade, Industry, and Energy. The funding was ultimately consolidated under a single organization -- the Electronic Display Industry Research Association of Korea (EDIRAK), which had been founded in 1990 as a public-private partnership to develop standards in the production of CRTs, of which Korea is a major producer.

The G-7 HAN Project

The G-7 HAN (Highly Advanced Nation) Project originated with a proposal in 1995 by the Minister of Science and Technology, Jin-Hyun Kim. It is a national mission-oriented project, the first of its kind in Korea. The G-7 part of the name

signaled Korea's desire to join the small club of powerful industrialized countries in the Group of 7 that met every year in a different location. The basic idea was to fund a series of programs that would make Korean science and technology strong enough to allow the country to participate as an equal with the advanced industrialized countries.

Kim's strategy for getting funds involved convincing the Economic Planning Board (EPB), the agency that controlled all public spending in Korea, that it would be a good idea to get the various ministries to cooperate in funding technology projects. The earlier pattern had been for the ministries to fund projects separately, and the result was a patchwork of programs that did not necessarily make any sense.

One specific concern expressed in the discussion of the G-7 HAN Project was growing Korean dependence on Japanese technology. This had come up initially in the context of Korean entry into DRAM production, where many of the tools for producing DRAMs were available only in Japan. When the same thing happened after Korean firms decided to produce TFT-LCDs, government officials became concerned about what they came to view as excessive dependence of Korean firms on the importation of tools and engineering advice from Japan. Japanese firms had a number of natural advantages over U.S. firms in supplying the technology needs of Korean firms. Korean engineers, although largely trained in the United States, could read Japanese manuals easily and tended to prefer working with Japanese engineers and other business representatives because of the proximity of Japan and the similarity of Japanese and Korean business cultures.

Korean government officials responded by encouraging U.S.-Korean ties. Thus, one important aspect of the G-7 HAN Project was for the government to select priority areas for cooperation between the US and Korea and to facilitate that cooperation as part of the broader goal of building indigenous technology capacity in Korea. One of the priority areas chosen was flat panel displays.²⁹ The Minister of Science and Technology thought that it was crucial for the government to help pay for the costs of cooperation, especially organizational costs. He created the Korean-US Science and Technology Forum, an annual meeting for which Korea paid all the costs.³⁰ He thought that the private sectors of both countries should help to set priorities for U.S.-Korean cooperation. He also pushed for small meetings between MoST staff and representatives of Korean firms and universities to keep MoST up to date on technological challenges.

The G-7 HAN Project thus became the vehicle for the funding of interagency technological promotion activities. It later became the principal source of funds for government spending on the advanced display industry.

MoTIE's Initiative of October 1996

In 1995-96, Korea developed a growing trade deficit with the rest of the world (\$20 billion in 1996). Largely as a response to this, the Minister of Trade, Industry, and Energy announced the selection of 30 priority industries for special

governmental promotional activities in a report issued on October 14, 1996. There were three main categories of industries prioritized in the report:

- leading export industries;
- small- and medium-sized firms in high value-added businesses;
- promising/emerging industries.

One of the industries selected under the category of "promising/emerging" was flat panel displays.³¹

Shortly after the issuance of the October report, there was a meeting of representatives of industry, government, and academia to discuss the flat panel display industry. The participants agreed that Japan was the country to beat if Korea wanted to be a world class competitor. They also agreed that TFT-LCDs would be the technology of choice for computer monitors smaller than 20 inches; for larger monitors, the technology of choice was plasma display panels. The participants were unable to agree on what should be done in the area of a more speculative technology, field emission displays (FEDs), despite excitement about the future potential for FEDs in the United States.

There was plenty of internal governmental debate about how to achieve the goal of competing successfully with Japan. Many government officials thought that it was not wise for the bureaucracy to try to micromanage the actions of private firms. In any case, because of their growing economic power, the *chaebol* were unlikely to submit themselves to top-down management from government officials. Instead, they argued, the government should focus on technology education and generic technologies. It should try to prevent roadblocks for commercial development of new technologies. This was also the view generally taken by officials in MoST.

The opposing view, articulated mainly by officials in MoTIE, was that it was necessary to target specific industries for promotion in order to enhance the international competitiveness of Korean firms and to reverse the trend toward growing trade deficits (especially vis-à-vis Japan).³² Korean goods were no longer price competitive. Manufacturing workers were scarce with the unemployment rate in Korea at 2.5% and women choosing the services sector instead of manufacturing. Korean firms were increasingly forced to import low-wage workers from other developing countries. Engineering students were studying software instead of semiconductors, wanting to be the next Bill Gates.

EDIRAK

Despite the disagreement between MoST and MoTIE about how best to promote high technology industries, funding of the G-7 HAN Project was approved by the EPB. The 1995 total funding for the flat panel display portion of the G-7 HAN Project was \$10 million, out of a planned expenditure of \$220 million over five

years. 1996 funding consisted of \$4 million from MoST, \$3.8 million from MoTIE, and \$8.8 million (up to 90% of which could be in-kind) from EDIRAK members. Total funding in 1997 was to rise to \$71.6 million.

The resources are administered by EDIRAK, which has a governing board composed of the directors and presidents of member companies. On the government side, MoTIE has the principal responsibility for overseeing the project, with MoST as a cooperating ministry. Committees were formed within EDIRAK to determine priorities and to generate proposals. Final funding decisions are made by the governing board.

The four areas of current research interest are TFT-LCD, plasma display panels (PDPs), field emission displays (FEDs), and 3D displays. The main foci for TFT-LCD research at EDIRAK are backlights, polarizing filters, steppers, cleaning stations, glass cleaning, glass inspection systems, and photo resists.

The EDIRAK officials that we interviewed claimed that a major shared concern of the Korean firms in EDIRAK was their dependence on Japanese equipment manufacturers. The firms had spent over \$800 million on Japanese tools in 1996. This was one reason why EDIRAK and its members were interested in working with members of the United States Display Consortium (USDC), a cooperative industry-government group established in 1993 to build a U.S.-based infrastructure for high-definition display manufacturing. The USDC had been successful in creating some new strengths in TFT-LCD manufacturing equipment based on existing strengths in semiconductor manufacturing equipment. Until the formation of the USDC, U.S. firms had not been so active in developing ideas and products for LCD manufacturing.

When we asked our industry informants about this, they suggested that they were not so worried about dependence on Japanese suppliers and that they had had mostly good experiences in working with Japanese companies. They did not have confidence in U.S. suppliers because very few of them had worked with high-volume producers of TFT-LCDs. The Koreans' preferences were driven by the necessity of rapidly ramping up production of TFT-LCDs to remain competitive with Japanese firms, which required working with tools that had been tested in high-volume production.

Despite the skepticism of the Korean firms, EDIRAK officials pursued the idea of reducing dependency on Japanese suppliers by working cooperatively with USDC. On the American side, the appeal was market access and the opportunity to work with volume manufacturing. EDIRAK/USDC joint funding of projects was one result of the recent memorandum of understanding between the two organizations negotiated in the first nine months of 1996. Twenty-three members of USDC visited Korea in October 1996 to discuss possible collaborative efforts. Proposals for the first round of projects were due in April 1997.

It is still too early to know if EDIRAK will represent a significant contribution to the Korean infrastructure for TFT-LCDs. Overall, government intervention seems to have had only marginal influence on the TFT-LCD strategies of Korean firms.

The Advanced Display Industry in Taiwan

The Taiwanese story stands in marked contrast to that of Korea. As of Fall 1997, no Taiwanese firm had started high-volume production of notebook-size TFT-LCDs. Two firms, Unipac and Prime View, are producing smaller TFT-LCDs and are planning production of larger displays. A third company, Chunghwa Picture Tubes, produces STN-LCDs and has entered an alliance with a Japanese partner to produce TFT-LCD screens. Another STN-LCD producer, Nan Ya, has been negotiating to license TFT technology.³³

On the public side, the Taiwanese government has given a single government agency, the Industrial Technology Research Institute (ITRI), an unusual set of human, financial, and physical resources for promoting technology acquisition, development, and diffusion. ITRI's microelectronics research laboratory, the Electronics Research and Service Organization (ERSO), hires top engineers and gives them the wherewithal to set up pilot production facilities which may become (and have become in the past) full-scale operating factories. Indeed, we will show below that the private firms think of ERSO sometimes as a competitor rather than a supporter in their efforts to achieve international competitiveness. Taiwan unquestionably has the technological competence to produce large TFT-LCDs. The government has done much to encourage their production. Yet, as we will see, it has been a long time coming.

Unipac

The first volume producer of TFT-LCDs in Taiwan was Unipac Optoelectronics (known as *Lian You* in Mandarin). Unipac was affiliated with United Microelectronics Corporation (UMC), which became Taiwan's first private integrated circuit producer when it was spun off from ERSO in 1980.³⁴ UMC is a fast-growing company; its sales grew from nearly \$400 million in 1993 to \$950 million in 1995. Other investors in Unipac besides UMC include a variety of venture capital funds and the China Development Corporation, the investment arm of the island's dominant political party, which owns shares in many high-technology enterprises.

Unipac was founded in 1990 to make sensors for fax machines, but when the local market for that product failed to develop, its production was switched to TFT-LCDs. Volume production of four-inch screens for handheld televisions and similar portable applications began in 1994 on a first-generation production line at a rate of 2,500 sheets of 300mm x 400mm motherglass per month. Line 1 was located in the Hsinchu Science-Based Industrial Park (HSIP), where most of the rest of the country's high-technology electronics production is also located, and the cost of building the line was only \$80 million.³⁵

Unipac added 5.6" modules to its product line in 1996 and expanded capacity to 6,250 substrates per month. Unipac has long eyed entry to the notebook display market, but has so far hesitated in the face of rapid market changes. Starting in 1994, it developed 8.4", then 9.5" modules, and was contemplating a \$300 million investment in a new plant to be built in 1996. By mid-1995, Unipac had working prototypes of 10.4" displays, with plans for volume production by 1997, but the price for 10.4" displays had fallen from \$1,200 in late 1994 to around

\$500 in mid 1995. As the market began to shift rapidly to larger sizes, Unipac had to adjust its plans, shifting to 11.3", then 12.1" SVGA modules, which are currently planned for high-volume production in 1998.

Unipac recently diversified its display portfolio by agreeing to act as a foundry (i.e. on a subcontract basis) for a French firm, PixTech, which has developed a different type of display known as FED (field emission display). TFT-LCD and FED share several common technologies: thin film deposition, photolithography, driver attachment, and driver circuits. FED production in Taiwan will be done on a contract basis in an old fabrication facility vacated by UMC, which has also made a \$5 million investment in PixTech.

Unipac will also help produce yet another type of display, this time for an American company, Kopin. Kopin's product is a micro-display, primarily for use in portable products and video "eyeglasses." The actual display is only a quarter inch diagonally, but the user views the display through optical lenses than make it appear to be as large as 20 inches. The technology requires an initial stage of production in a silicon wafer foundry and a second stage involving transfer of the circuit from the silicon wafer to a glass substrate, making the UMC-Unipac combination ideal. As it did with PixTech, UMC invested directly in Kopin.

Prime View International

Prime View International (PVI, or *Yuan Tai* in Mandarin) is an innovative start-up firm founded by four individuals, one of whom had a patentable idea for reducing the number of driver ICs used in production of the TFT-LCD module. In order to prove the feasibility of the concept, they were able to use an existing pilot line at ERSO, a semi-public microelectronics research facility. Armed with positive results, the founders received the majority of its funding from Yuen Foong Yu (YFY), Taiwan's largest producer of paper products (with 1995 revenues of nearly \$800 million), which wanted to diversify into the high-technology sector. A minority shareholder is Chiao Tung Bank, which the government has used for venture capital investments and loans to strategic industries.³⁶

Prime View was established in 1992, and construction of a new plant in the Hsinchu Science-Based Industrial Park began in October 1994. By late 1996, about \$140 million had been spent for the plant and for one second-generation production line with a capacity of 6,000 sheets of 370mm x 470mm motherglass per month. Most of the production equipment is Japanese (the only American tool being a Photon Dynamics array tester). Prime View's first high-volume product is a 5" module which can be produced 15-up and which is suitable for use in small TVs and arcade games. About half of sales are in the local market, with sales to Japan building slowly as the company works through the lengthy qualifying process of Japanese buyers. Prime View recently added smaller display sizes (1.8" and 2.5" extra-high-resolution) designed for the camcorder and digital camera markets to its product line, as well as a new 6.4" format.

Prime View has publicly announced that it will begin sampling 12.1" SVGA displays by the end of 1997 and is also looking at larger screen sizes. Line 2 will

be established in the existing plant. Because of the stability of its production process, Prime View was hired to serve as a foundry for an ERSO research consortium testing a 10.4" design (discussed below). Part of Prime View's delay in entering the notebook display market is attributable to concerns over the stability of third-generation equipment.

Prime View continues to be an innovative firm. Besides the original idea around which the company was started and which has received US patents, they developed their own manufacturing process, designed their own backlights (which they outsource locally), and developed their own chip-on-glass technology for reducing the module size of smaller displays.

CPT

A firm which is only now planning to begin production of TFT-LCDs is Chung Hwa Picture Tubes (CPT), a majority-owned affiliate of Tatung, one of Taiwan's older electronics firms. Tatung, a manufacturer of consumer products, is also one of Taiwan's largest enterprises, with over \$1.5 billion in sales in 1995. Unlike Prime View and Unipac, which are relatively young firms, CPT was established in 1970 to produce CRTs for television sets with technology licensed first from RCA, then later from Toshiba, which still maintains a small shareholding in Tatung. CPT claimed 32% of the world market for color CRTs at the end of 1994, but, in line with the Bernard and Ravenhill hypothesis, the company's prospects have been limited by a continued dependence on foreign technology. In CRTs, this meant that Toshiba would not license the designs for its highest-value models.

Recognizing that CRTs would face increasing competition from flat panel displays, CPT began to study liquid crystal technology in 1988.³⁷ Although it tried to license TFT-LCD technology from its CRT partner, Toshiba, CPT had to settle for STN technology, a technology Toshiba would cease to produce in Japan because of its declining market value.

CPT has struggled with the rapid changes in the flat panel display market. It built a \$100 million first generation production line using 300mm x 350mm motherglass in Taoyuan County, near Taipei, for the 9.5" design it had licensed, but by the time it was operational in mid-1995 the market standard had already become 10.4". CPT was able to obtain a design for the larger format from Toshiba, only to find the market shifting again. By the time CPT was able to design an 11.3" module in-house and put it into production in late 1996, demand had shifted to 12.1" displays, which CPT was able to design and produce by mid-1997. The line currently uses either 300mm x 370mm or 370mm x 470mm glass to produce displays ranging from 9.5" to 15.0", with re-tooling occurring as circumstances warrant. The potential capacity of the plant is 40,000 substrates per month.

Despite the company's difficulties in the STN-LCD market, the need to enter into TFT-LCD production was felt strongly by C.Y. Lin, CPT's president and son of Tatung's chairman.

In April 1997, CPT announced a strategic alliance for TFT-LCD production using LCD technology from Advanced Display Inc. (ADI), a joint venture between Asahi

Glass and Mitsubishi Electric. Mitsubishi is providing extensive engineering support and training, and is expected to take up to 30% of CPT's TFT-LCD output. 4-up production of 12.1" displays on 410mm x 520mm substrates ("generation 2.5") on a line installed in an existing building located next to the STN-LCD plant is scheduled to begin in late 1998. Planned capacity is for 30,000 substrates per month, and the total investment is \$550 million.

Nan Ya Plastics

The latest Taiwanese entrant in the TFT-LCD market is Nan Ya Plastics, whose story is similar to that of CPT. Nan Ya, an older and larger firm (established in 1958, with 1995 revenues of over \$3 billion) than the other three firms described above, is part of Taiwan's largest business group, the Formosa Plastics petrochemical conglomerate, whose combined 1995 revenues exceeded \$10 billion.

Nan Ya's primary business is the production of polyvinyl chlorides (PVCs) and other plastic products, but in the 1980s the company began to diversify into materials for the electronics sector, such as bare circuit boards. Nan Ya started research on liquid crystal displays in 1991, as an extension of the diversification process.³⁸ After determining that STN-LCDs were more feasible than TFT-LCDs given Nan Ya's capabilities at the time, they began to develop STN-LCD technology internally. In 1992, pilot production of 9.5" and 10.4" monochrome STN-LCD screens began at a plant located Taipei with an investment of about \$7 million. This line could run 7,500 sheets per month of 300mm x 350mm motherglass. A second, fully-automated plant, costing about \$40 million, was built in 1994 in Taoyuan County with a capacity of 50,000 sheets per month of either 300mm x 350mm or 300mm x 400mm glass. The company began production of color 10.4" STN-LCDs in 1996, and added 11.3" displays in 1997, while developing 12.1" displays along with smaller sizes for non-notebook applications.

In 1994, about the same time it was setting up a subsidiary to produce memory chips in an alliance with Japan's Oki Electric, Nan Ya was reported to be trying to license TFT-LCD technology from Japanese firms. However, plans were not yet set when Nan Ya's executive vice president Winston Wang, son of the founder of Formosa Plastics Group, was banished from the firm in 1995 under a cloud of scandal. The company is still considering the right entry strategy for the TFT-LCD market.

The Role of Government Policy in the Taiwanese Display Industry

If production of large TFT-LCDs has been slow to materialize in Taiwan, it's not for lack of effort by the government.

The primary agencies for high-technology industries are located in the Ministry of Economic Affairs (MoEA). Since the 1970s, the MoEA has promoted a shift to the production of higher-value-added products. Because TFT-LCD production tends to be highly automated, local production would increase the value-added per

worker in line with rising wages, and help fill the gap left as Taiwanese firms transfer more labor-intensive manufacturing to offshore plants in lower-wage countries.

The island's trade deficit with Japan provides an additional motivation specific to TFT-LCDs. Taiwan has become one of the world's largest designers and assemblers of notebook computers. 1993 production exceeded one million units, and by 1996, the number of units produced had risen to 3.8 million -- roughly 32% of world production -- with a value of \$5.3 billion.³⁹ About 97% of the Taiwanese output was exported, most of it to well-known computer companies like Dell and Compaq. The higher-priced models use TFT-LCDs, which account for 20 to 30% of the cost of the final product. In 1996, over half of the notebook PCs assembled in Taiwan featured TFT-LCD screens and the ratio of TFT to STN screens continues to grow.⁴⁰

Success in the notebook computer industry has negatively affected Taiwan's trade on the input side. In 1993, Taiwan's trade deficit with Japan topped \$14 billion, and its imports of TFT-LCDs that year were valued at \$330 million. In 1996, with the deficit just under \$14 billion, TFT-LCD imports (still mostly from Japan) totaled nearly \$1.4 billion, and a government forecast predicts an increase to more than \$2 billion by 2000 in the absence of domestic production.⁴¹

Taiwan has offered investment incentives (tax holidays, accelerated depreciation, etc.) since 1960. More carefully targeted incentives for product development and high-technology investment began to appear in the 80s. A major program launched in 1992, the Key Components and Products Development program, included TFT-LCDs on a list of 69 components that Taiwan currently imported but could produce locally and provided tax preferences, subsidized loans, and research grants for private companies willing to localize any of the items on the list. In mid-1997, MOEA again included LCDs on a shorter list of top priority technologies qualifying for research incentives.⁴²

Our interviewees indicated that the rules for tax benefits were transparent and non-controversial. The investment decisions of numerous government-connected financial institutions were less transparent, and we were unable to obtain much information about them from our interviews. We will therefore focus our attention on the most visible aspect of the government's efforts in support of advanced displays, namely the Electronics Research and Service Organization (ERSO), the official lab most directly concerned with TFT-LCD technology within the Industrial Technology and Research Institute (ITRI), which is in turn part of the MoEA.

ERSO was involved in two important ways in the drive to localize the TFT-LCD industry in Taiwan: through direct development of the technology, and through efforts to convince private firms to invest in production. Before considering each of these, we will first take a closer look at ERSO itself, which is a somewhat unusual organization.

The Electronics Research and Service Organization

ERSO, a research lab which performs contract work for both the government and for private industry, is the focal point of the Taiwanese government's efforts in microelectronics. ERSO provides the technical support for most agencies involved in setting industrial policy, including MoEA's Office of Science and Technology, the Industrial Development Bureau (a branch of MoEA responsible for investment policy), and the National Science Council, a cabinet-level agency which administers the Hsinchu Science-Based Industrial Park. By helping to flesh out all proposals which are made, ERSO is able, in part, to shape them.

ERSO's corps of engineering talent is widely recognized to be among the island's best. ERSO essentially has the pick of the island's engineering graduates because of its ability to offer a military service exemption, and it has sought to keep them productively engaged. ERSO tends to choose projects that are intellectually challenging and therefore closer to the cutting edge of international research. For example, ERSO began its LCD research program in 1986, years before Taiwan's emergence as a major player in the notebook computer market. This role is particularly critical in Taiwan where the firms tend to be small and risk-averse; few local firms can afford to have as many engineers as ERSO doing forward-looking research.

ERSO was established in the mid-1970s to help create an integrated circuit industry in Taiwan. It first licensed older-generation technology from RCA, and set up a pilot fabrication line, which it spun off in the early 1980s as United Microelectronics Corporation (UMC). UMC is a successful supplier of specialized "application-specific" ICs to the domestic and export markets, and, as we have seen, it later established Unipac, the first TFT-LCD producer in Taiwan.

ERSO's next major spin-off, Taiwan Semiconductor Manufacturing Corporation (TSMC) occurred a few years later. It was a partnership with Philips of the Netherlands for the creation of the world's first IC foundry, and has been hugely successful and widely imitated. It was around this time that ERSO also launched its first program for the development of liquid crystal display technology (discussed below).

Two points relating to ERSO's experience with ICs are of interest here. First, ERSO initially tried to interest local firms in its IC technology to no avail. It was only after UMC and TSMC had proved successful that private Taiwanese capital was channeled into IC production. Today, Taiwan has nearly twenty chip plants in operation, and announcements appear regularly about new investments. Thus a major commitment of resources by the government was necessary before private firms were convinced that the industry was viable in Taiwan.

As we will show below, the private sector has been resistant to government exhortations to plunge into the flat panel display industry. However, now that firms like Unipac and Prime View have led the way, the pace of announcements about TFT-LCD investment has decidedly quickened.⁴³ During the writing of this article Teco, a large producer of electrical and electronic goods, and Chi Mei, a large petrochemicals firm, have announced intentions to invest in TFT-LCD

production, although details, particularly about technology partners, have not been announced.[44](#)

A second point is that ERSO's position with respect to the private sector has changed markedly since its days of launching the IC industry.[45](#) In the case of ICs, ERSO had the field all to itself for over a decade. Today, Taiwan's industrial landscape is densely populated with high-tech firms who view ERSO's more entrepreneurial efforts through a competitive eye. In 1993, a \$400 million dollar public investment in TFT-LCD production was proposed, but it was rapidly shot down by private firms with whom ERSO now consults regularly as part of a formal review process.

The firms claimed, among other things, that the money would be more efficiently spent if given directly to the private sector. In some ways, it was a mark of ERSO's past successes that private firms were powerful enough to make such claims credibly. In other words, success has forced ERSO to develop new strategies for achieving its goals.

Direct Development

ERSO's development of TFT-LCD technology dates back to 1986.[46](#) In 1988, the government enacted the "Optical Information Project" covering several technologies, including LCDs. Production of TFT-LCD requires at least five major technology categories: microfabrication (for thin-film transistors), IC design (for driver chips), panel assembly, module packaging, and related materials (e.g., color filters). Successful production of TFT-LCDs requires not just a good product design but also a viable manufacturing process. ERSO's first prototypes, starting in 1989, were 3" polysilicon high-resolution displays for use in projection TVs. Progress was also made in ancillary technologies such as color filter processing and "chip-on-glass" fabrication methods in which the driver ICs are directly mounted on the glass panel of the display to reduce the complexity of interconnecting the display to the rest of the device.[47](#)

ERSO began a new \$92 million, four-year research project in 1993.[48](#) In 1994, it showed a prototype 10.4" TFT-LCD, which became the basis for an effort to interest local companies in the technology (discussed below). ERSO worked on wide-viewing-angle TFT-LCDs in 1995 and on reflective monochrome TFT-LCDs in 1996. Reflective TFT-LCDs do not require backlights and hence consume less battery power than conventional TFT-LCDs. They are also viewable under bright light with an acceptable contrast ratio. Reflective TFT-LCD research is also underway in Japan and Korea, but ERSO believes that parallel development of the technology in Taiwan will facilitate its eventual adoption by local firms. ERSO is also developing a much more speculative technology, field emission displays (FEDs). Starting in 1992, ERSO began assembling a team. In 1996, they demonstrated a working 3" monochrome prototype for which several patents have been obtained. Although FEDs could potentially compete with TFT-LCDs in the high-end notebook computer market, they are appearing in other applications first. Small FEDs are appearing in medical, scientific, and factory

automation equipment. Other potential applications include navigational displays in cars and trucks.

Alliance Formation

Because Taiwanese firms are often too small to tackle major technology development projects, the government has frequently tried to bring them together in cooperative alliances, with varying degrees of success.⁴⁹ In the case of TFT-LCDs, success has been elusive.

In 1992, the Industrial Development Bureau (IDB), an agency within the MOEA whose responsibilities include arranging preferential loans for manufacturing investments in targeted sectors, called publicly for firms that were independently developing LCD technology to pool their resources. At a meeting in March 1993 attended by all of the island's existing and potential display producers, ITRI disclosed its strategy for the TFT-LCD industry, pursuant to the government's new policy of having the private sector take the leading role in technology development. It would fund preliminary research at ERSO (the four-year program mentioned above) and then the technology would be further developed by a private-sector alliance.

In 1993, a TFT-LCD alliance was formed in response to the IDB's exhortations. The new organization, Mandarin Display Manufacturing Corporation, was spearheaded by Champion Consulting, a local venture capital firm. Champion Consulting's chairman, Hu Ting-Hua, was also chairman of Macronix, one of the earliest private firms to build an IC factory in Taiwan. The goal was to raise about \$500 million to build a TFT-LCD plant. UMC, CPT, Nan Ya, Picvue (a producer of small STN- LCDs), and TSMC (the IC joint venture with Philips) were all involved, paying about \$40,000 each for the right to participate. Among other things, the members were split over what technology to use; Japanese technology was not available at the time, and ERSO's technology was not yet ready to be commercialized. Philips was interested in licensing to the group its modified thin-film technology, which it later deployed at its own plant in Europe, then eventually abandoned. The members met every month or two in meetings staffed by ERSO and also traveled to the Netherlands to see Philips' pilot production facility. In the end, the member firms were unable to agree on what direction to pursue, and the alliance was disbanded.

Two years later, ERSO brought firms together again to study its internally developed 10.4" TFT-LCD. CPT, Nan Ya, Acer Peripherals (an affiliate of Taiwan's largest PC firm), and China Steel (a government-owned firm in the midst of being privatized and which had recently diversified into the production of silicon wafers for the IC industry) participated, reportedly paying about \$150,000 each and dedicating a number of engineers to the project.⁵⁰

This group continued to develop ERSO's technology, contracting with Prime View for sample runs. ERSO advocated joint funding of pilot production under ERSO supervision and then spinning off a private joint venture, much in the way it had done earlier with IC technology, but the idea was not accepted by its partners.

The alliance ultimately ended with no single company willing to move to the second phase and license the ERSO technology for high-volume production. The lack of success in these alliances is perhaps not surprising. In R&D consortia in other countries, such as Japan's VLSI Project of the mid-70's or the United States' ongoing SEMATECH consortium, the focus is on pre-competitive research, with members receiving preferential access to results that they then use to develop differentiated products. Such consortia do not generally concern themselves with preparing products for high-volume production.⁵¹ Since ERSO's efforts were aimed at bringing existing technologies to the verge of mass production, the two alliances -- particularly the second one centered on ERSO's technology -- required firms to work together at a level too close to their competitive core.

At least one participant in the meetings surrounding these alliances described them as useful for learning about the industry, but, on the whole, the process seems to have led to a dead end in Taiwan's efforts to spur local production of TFT-LCDs.

Discussion of the Two Cases

The Korean and Taiwanese cases differ sharply in the timing and size of investments in TFT-LCD production (see Table 2). Korean firms invested earlier and more than their opposite numbers in Taiwan. Korean investments have in fact led the *chaebol* to all but close the technology gap with their Japanese rivals, calling into question the claims of the Asia skeptics.

Before directly discussing the technology choices of firms, we first describe how the observed differences flow logically from the different policy histories of the two countries. Policies determined industrial structure, which conditioned firm strategies.⁵² Structure and firm growth have in turn conditioned the need for, and ability of, government to intervene.

Table 2. TFT-LCD Factories in Korea and Taiwan

	1992	1993	1994	1995	1996	1997	1998
KOREA							
Samsung	pilot (1991)	Gen.1 2,400 10.4"		Gen.2 20,000 10.4"		Gen.3 25,000 12.1"	Gen.3.5 30,000 13.3"
LG	pilot (1990)			Gen.2 10,000 10.4"		Gen.3.5 30,000 12.1"	Gen.4 25,000 13.3"

Hyundai	US pilot			Gen.2 12,000 10.4"	Gen.3 5,000 12.1"		Gen.3.5 30,000 13.3"
TAIWAN							
Unipac			Gen.1 2,500 4.0"		Gen.1 3,750 5.6"		? ? 12.1"
PVI					Gen.2 6,000 5.0"	same line 12.1"	
CPT				Gen.1 40,000 9.5" STN	same line 11.3" STN	same line 12.1" STN	Gen.2.5 30,000 12.1" TFT
Nan Ya	Gen.1 7,500 9.5" STN		Gen.1 50,000 9.5" STN		same line 10.4" STN	same line 11.3" STN	

Note: Each cell gives the generation, capacity (in substrates per month), and primary display size produced (TFT-LCD except where indicated). The year is the date of operation. Figures for years after 1996 are the authors' estimates.

Sources: Business press and interview materials.

Korea and Taiwan: Contrasting Studies in Development

One of the obvious differences between the firms in our case studies is size. Among Korean firms, the two principle producers, Samsung Electronics and LG Electronics, had 1995 revenues of more than \$14 billion and \$6 billion, respectively. As we have seen above, while one Taiwanese entrant --Nan Ya Plastics -- has comparable cash flow, the other Taiwanese firms are an order of magnitude smaller. The Korean firms are thus more similar in size to their Japanese rivals. The largest Japanese producer (by market share) is Sharp, which had total revenues of over \$10 billion, small by comparison with some of its domestic rivals (such as Matsushita and NEC) who had sales two or three times larger.[53](#)

The average size difference between Korean and Taiwanese firms is an economy-wide phenomenon. In 1983, the sales of the top 5 business groups in Korea were equal to 52% of gross national product, rising above 90% for the top 50, whereas in Taiwan the sales of the top five groups amounted to 10% of GNP, rising to 32% for the top *hundred*.⁵⁴

The differences in industrial structure are largely policy-driven. In Taiwan and Korea, each government launched an export drive in the 1960s⁵⁵ and utilized the commanding heights of the economy to execute policy. In both cases, credit rationing was an explicit part of the policy package.⁵⁶ However, while the Korean government used its control of the finance sector to direct credits to a few favored firms which became larger and larger,⁵⁷ the Taiwanese government, exercising the same degree of control over the financial system, avoided fostering a comparable set of national champions. As evidence that the financial sector is indeed a significant source of the cross-national differences, it is worth noting that, in 1985, the debt-to-equity ratio of Korean manufacturing firms was nearly 350, compared with 120 in Taiwan.⁵⁸

In Korea, the government, despite efforts at financial deregulation, continued to provide access to cheap credit into the 1990s.⁵⁹ This easy access to debt capital has been an important source of competitive strength for the Korean *chaebol*, although it has also introduced a tendency for overcapacity in industries that the *chaebol* enter. None of the firms we talked to suggested that they were constrained by the availability of investment capital. All of them spoke of the ability of top management to follow its vision of future markets, even if that sometimes meant investing in products, like DRAMs and TFT-LCDs that experienced cycles of under- and oversupply and therefore did not generate a steady flow of profits. In Taiwan, we were told repeatedly that short-term performance was a concern in formulating strategy. Taiwanese firms not only have a higher reliance on equity markets, they also experience lower cash flow from the very fact of being smaller. These differences in industrial structure give rise to different production structures, as Korean firms have specialized in more capital-intensive, higher-value-added goods than their Taiwanese counterparts. An analysis of imports from both countries to the United States in the 1980s showed that Taiwanese exports reflect more product variety (a broader range of sub-categories within each product group), while Korean goods are more concentrated in the higher-value varieties in each product group.⁶⁰

The differences in general export patterns hold true in the electronics sector as well. Thus Taiwanese firms account for significant shares of world output for a wide variety of computer-related items, including computer motherboards (74%), keyboards (61%), monitors (53%),⁶¹ modems (41%), video cards (55%), and desktop scanners (53%), and, with support from ITRI, are moving into additional sectors, such as CD-ROM drives and networking equipment. By contrast, Korean firms have their most significant share of world output for capital-intensive, high-value-added components such as CRTs and memory chips. As shown in the above case studies, this dichotomy holds even within a single

product category such as TFT-LCDs, where the Taiwanese have so far concentrated on smaller display sizes, which have a lower value per square inch than notebook computer displays.⁶²

Since the Korean case fits the ideal Gerschenkronian pattern of large-scale, capital-intensive latecomer industrialization,⁶³ the Taiwanese case seems to be the one to explain. Explanations that have been advanced include the "Chinese family system" of equal inheritance among sons⁶⁴ and the desire of the mainland-originating ruling party to prevent the creation of large, native Taiwanese firms which might in turn oppose it.⁶⁵ Factors such as these led to an environment where the desire of individuals to be their own boss -- exemplified by the proverb that "it's better to be the head of a chicken than the tail of an ox" -- could be readily indulged. Rather than expand, a typical Taiwanese firm will splinter off new activities into separate corporations (either intentionally or through employee defection), which may be linked financially to the original firm but which strategize separately.

The role of government has been forced to adapt to these differences in structure.⁶⁶ Governments in both Korea and Taiwan are continuing to use tax incentives and administrative guidance to promote high-technology industries, but direct intervention has mostly been absent or unsuccessful in the case of TFT-LCDs. In Taiwan, the existence of ERSO's pilot facility was critical to Prime View's ability to verify its process technology and secure funding, but otherwise the government's production has not given rise to private activity.

However, the limited role for direct intervention has different explanations in the two cases. In Korea, firms did not require much government assistance. In Taiwan, it was more a case of government inability either to act independently (i.e. to directly invest and then spin off) or to overcome collective action problems among self-interested firms.

These patterns hold true for public technological support in general. Whereas the share of government funding in R&D in Korea has been less than 20% since the late 1980s, the government's share in Taiwan has remained about 50% (compared with about 30% in Japan and the US).⁶⁷ In Korea, where the firms have adequate resources to develop and pursue their own strategies, public research has been increasingly limited to more basic areas. By contrast, Taiwanese firms are less able to shoulder the burden of pursuing new technologies, and the government has responded by undertaking applied and developmental research and by coordinating industrial alliances to help firms to overcome the disadvantages of their small size.

Technological Choices in Korea and Taiwan

We will now focus more directly on technological strategies in the two countries, where the differences are largely driven by the market structure differences detailed earlier. Our case studies suggest that Korean firms favor large-scale commitments, vertical integration, and direct competition with leading firms, while virtually the opposite is true for the Taiwanese.

The Korean strategy in high-technology sectors has been massive entry in established technologies where large-scale investment is the principal requirement for participation. Taiwanese firms have met success through niche strategies, seeking opportunities with relatively low initial commitments of resources, as exemplified by the small-scale entry of Unipac and Prime View, which chose to start out producing small-size displays.⁶⁸

Whereas the Koreans excel in mass production, the Taiwanese are stronger in flexible specialization. Taiwanese firms have developed a business style that Lam and Lee (1992) call "guerrilla capitalism."⁶⁹ Guerrilla capitalist firms are small, flexible, and responsive to market shifts. In other words, such firms are focused on the exploitation of short-term profit opportunities and demonstrate a "lack of commitment to any particular product or industry."⁷⁰ Although this description seems inapt in the case of well-established firms like CPT or Nan Ya, it seems to fit Unipac, the first commercial producer of TFT-LCDs in Taiwan. Unipac was originally established to produce a key part for fax machines, and only when the local downstream industry failed to develop did it shift its purpose to displays. More recently, Unipac has diversified into other display technologies -- microdisplays and field emission displays -- as opportunities arose rather than making a focused push into notebook computer displays as Korean firms were doing.

Korean firms make their choices in an overall optic of vertical integration, encompassing intermediate inputs, particularly color filters, and downstream products such as portable computers and desktop monitors. Vertical integration is the exception rather than the rule in the fragmented Taiwanese high-tech sector. For advanced displays, Taiwan's lack of vertical integration has several consequences. A lack of upstream integration means that key inputs need to be purchased on the open market. This may enhance a firm's flexibility if the technology changes rapidly, but it can be a liability when shortages develop in input markets, as has occurred with color filters. The lack of downstream integration prevents Taiwanese firms from internalizing the benefits that might flow from access to the latest displays. In notebook computers, 50% of the profit from each new generation is realized in the first three months after it's first marketed.⁷¹ While Taiwan's success in the notebook computer industry suggests that display access is not vital, access to the largest, best-performing displays may give Korean firms a foothold in the most profitable segments not only in portable computers but also in the nascent market for flat desktop monitors. Differences in integration also affect access to skilled labor. Each *chaebol* encompasses a range of activities and can re-assign engineers with the requisite electrical, chemical, and mechanical engineering skills based on group priorities, but Taiwanese firms are more narrowly focused and compete against each other for engineers on the open market. This further disadvantages Taiwanese display producers, who are not yet earning sufficient returns to compete aggressively for talent. For example, a lack of engineers for module customization limits the ability of display firms to expand their marketing efforts.

Integration also affected reasons for competing in the industry. As detailed in the case studies, Korean firms generally reported entering the TFT-LCD industry as part of a long-range vision for the business group's future. With the exception of CPT, which is defending against the possible obsolescence of its role as a major supplier of CRTs, Taiwanese firms are generally investing in TFT-LCD production as a horizontal diversification. Several of our Taiwanese informants mentioned that local production of TFT-LCDs would be good for the country. The political motivation of the Taiwanese seems to be a weaker driver than the competitive goals of the Koreans.

Another difference is that Korean firms court head-to-head competition with market leaders, particularly the Japanese. The Koreans generally license when they must, then undertake extensive internal development so that future partnerships can be on an equal footing, like the ties between Samsung and Fujitsu or between LG and Alps. The strategies of Taiwanese firms typically involve complementarity rather than direct competition, as exemplified by the recent alliance between CPT and a Japanese partner (ADI), as well as by the foundry strategy (for FEDs and microdisplays) of Unipac.⁷²

We next turn to the implications of these technology choices within the Asia skepticism and globalization frameworks discussed in our introduction.

Paul Krugman claimed that technological gaps are not shrinking between the East Asian NICs and more advanced countries. Although we are looking at only one narrowly-defined sector, and Krugman accepts that "technology may have diffused in particular industries," our case studies do at least suggest a response. At the same time, we can ask if the "flying geese" formation is locked in, as Bernard and Ravenhill claim.

Closing technological gaps seems to depend on three factors -- capabilities, capital, and technology. As we saw above, Korean firms typically have a wide range of engineering capabilities available within the business group, whereas Taiwanese firms must attract such capabilities on the open market or develop them internally. The Korean firms in our sample had ready access to financial capital, which they used both to acquire technology and to invest in it at an efficient scale. They entered the market for TFT-LCDs at a time when licensing all the necessary know-how from Japan was not feasible. Through a combination of alliances with U.S. firms, internal development, and purchase of production equipment (with subsequent supplier support), they bridged the gap. The success of Samsung in producing notebook displays competitively in 1995 signaled the end of Japanese control over TFT-LCD production. Alliances linking Samsung and LG with secondary Japanese producers like Fujitsu and Alps is further evidence of gap closure. There is even limited evidence of technological leapfrogging, namely LG's willingness to work with Photon Dynamics to develop new array test equipment that allows the production of zero defect displays. Korean firms have also adopted a risky strategy of investing relatively more of their capacity in the larger motherglass sizes (generation 3.5 and higher) best suited to displays for the desktop monitor market, which has yet to materialize.

Several Japanese firms, having invested earlier, are committed to the smaller substrates which are most suitable for notebook displays.

Although TFT-LCD is a narrow industrial classification, Korean production of this product is a significant sign of the vulnerability of the "lead goose." First, many Japanese electronics firms have committed major resources to this technology in the hope that it would provide a long-term stream of economic rents. Second, control of core components like advanced displays is a key Japanese strategy for competing in various multimedia systems businesses. The surprisingly successful entry of the Koreans, following which prices rapidly fell and general availability increased, represented a serious setback on both counts.

In contrast with the Koreans, the individuals we interviewed in Taiwan expressed consistently that they did not seek to invest in latest-generation equipment, preferring stabilized generations leading to quick implementation and less uncertainty. With mature technology, display production becomes less of an engineering and more of a process management problem, drawing on the strengths of these companies. But at the same time, the companies were falling further behind the market leaders, who were gaining the benefit of extensive learning-by-doing.[73](#)

An important question is whether our finding of Taiwanese reluctance to invest at the technology frontier generalizes to other key sectors of the Taiwanese electronics industry.[74](#) The available evidence is mixed. Taiwan's best-known electronics company is Acer, a company which has proclaimed that its business plan for the PC industry is borrowed from McDonalds,[75](#) and which has staked its next-phase growth plans in part on an ultra-low-end PC called AcerBasic.[76](#) On the other hand, a number of Taiwanese IC producers (TSMC, Winbond, and others) have announced their intentions to build fabrication plants using 12-inch wafers, a decidedly unsettled technology. A broader study would be needed to resolve the question.

To sum up our findings within the Asia skepticism framework, the persistence or disappearance of technological gaps depends mostly on conditions in the follower countries rather than on the technology strategies of the leaders. Cheap credit and the aggressive conglomerates it funds permitted the Korean display industry to rapidly catch up with the Japanese leaders. Taiwan's fragmented market structure appears to be the chief impediment to a similar feat. In this sense, the technological gap framework seems more fitting than the "flying geese" metaphor. It is our belief, however, that the pessimistic conclusions of both schools are probably over-reliant on the analysis of historical data.

Finally, let us reconsider the case studies through the "globalization" lens of Borras and Zysman where market power within cross-national networks is the source of wealth creation.

Both Korean and Taiwanese firms have long participated in cross-national networks, typically producing components, sub-assemblies, and even entire systems for sale under the brand names of more-established firms. In their turn,

they have developed their own networks through investments in ASEAN and mainland China.

The Korean push into advanced displays -- with its associated downstream development of new models of notebook computers, LCD monitors, and expanded advertising campaigns -- can be seen as an effort to become a network leader through control of a core component. In fact, Samsung was able to sell much of its early output of TFT-LCD screens to Taiwanese firms by "bundling" them with the firm's DRAMs, which were in short supply at the time. This example shows the importance of the market power perspective as a framework for understanding technological choices and their consequences. Taiwanese firms have become indispensable partners for firms in the United States, Europe, and Japan. Japanese computer firms turned en masse to Taiwanese OEM suppliers to speed their re-entry into the personal computer market a few years ago. But with the exception of Acer, Taiwanese firms have mostly been unable to develop sustainable leverage within their networks, and their unwillingness or inability to develop key assets such as control over the core components in the systems they produce will most likely keep them in a subordinate position.

Conclusions

We have so far accentuated the point that Taiwanese display producers have adopted a slower approach to technological catch-up than their Korean counterparts, making the best of a mid-level position in the cross-national networks that characterize the IT industry. It is far too early to declare either approach a success or failure. Such a declaration would be wide of the mark in any event, because the strategies of firms in each country draw on their respective strengths -- skill in volume manufacturing in the case of Korea, and skill in flexible specialization in the case of Taiwan. For either country, imitating the strategy of the other would court disaster. Both countries have achieved an outstanding record of economic growth in a context of increasing democratization, and it would be presumptuous indeed to point to one system over the other as superior. Furthermore, our focus on a capital-intensive product has naturally favored the Korean conglomerates, whereas a focus on more design-intensive products such as computer motherboards would tell a different story.

Finally, it's worth noting that the current TFT-LCD leader, Sharp, began mass-producing 3" displays in 1987 before developing the capability of producing notebook-size panels in 1990. Thus it would be a mistake to fault the "slow and steady" strategy of the current Taiwanese producers of TFT-LCDs.

By way of conclusion, we would like to turn our attention briefly to the United States. We had anticipated the similarity we observed between the Korean and Japanese firms in our study, but we were somewhat surprised by a corresponding similarity between the Taiwanese and American firms. Short-term financial considerations, difficulty in raising capital for volume production, and

fierce competition for engineering talent are among the many commonalities. However, American firms are generally less willing to enter into complementary, technology-importing relationships like that between CPT and ADI. It should not be surprising, therefore, that America has had at least as much difficulty promoting a domestic display industry as has Taiwan.

Interestingly however, American policy for the display industry (i.e., support of suppliers through USDC) more resembles that adopted in Korea (through EDIRAK). Although pursuit of technological independence is common to both cases, the American choice is probably due to an earlier favorable experience with a similar policy for the semiconductor industry (SEMATECH) as compared with the Korean desire to reduce Japanese imports. Neither the U.S. nor Taiwan is likely to use public funds to replicate the massive private investments undertaken by the Korean chaebol (who, as we saw earlier, were aided by the government's loose credit policies), which might be the only way that US and Taiwanese companies -- for better or worse -- would find themselves with the Koreans at the "bleeding edge" of the advanced display industry.

REFERENCES

- Anchordoguy, Marie 1989: *Computers, Inc.: Japan's Challenge to IBM*. Cambridge, Mass.: Harvard University Press.
- Bernard, Mitchell and John Ravenhill 1995: "Beyond Product Cycles and Flying Geese: Regionalization, Hierarchy, and the Industrialization of East Asia," *World Politics*, 47 (January), 171-209.
- Borrus, Michael 1988: *Competing For Control: America's Stake in Microelectronics*. Cambridge, Mass.: Ballinger Publishing.
- Borrus, Michael 1994: "Left for Dead: Asian Production Networks and the Revival of U.S. Electronics," in Eileen Doherty (ed.), *Japanese Investment in Asia: International Production Strategies in a Rapidly Changing World*. Berkeley, Calif.: Berkeley Roundtable on the International Economy.
- Borrus, Michael and Jeffrey A. Hart 1994: "Display's the Thing: The Real Stakes in Conflict Over High-Resolution Displays," *Journal of Policy Analysis and Management*, 13, 21-54.
- Borrus, Michael and John Zysman 1997: "Globalization with Borders: The Rise of Wintelism as the Future of Industrial Competition". BRIE Working Paper #96B. Berkeley, Calif.: BRIE (forthcoming in *Industry and Innovation Journal*).
- Castellano, Joseph A. 1997: "Flat Panels Vs. CRTs -- The Future," *Communications Industries Report*, 14 (September), p. 1.
- Chen, Cheng-Fen and Graham Sewell 1996: "Strategies for technological development in South Korea and Taiwan: the case of semiconductors", *Research Policy*, 25 (August), 759-783.
- Chu, Yun-han 1994: "The Realignment of Business-Government Relations and Regime Transition in Taiwan," in Andrew McIntyre (ed.), *Business and Government in Industrializing Asia*. Ithaca, N.Y.: Cornell University Press.

Cummings, Bruce 1984: "The Origins and Development of the Northeast Asian Political Economy: Industrial Sector, Product Cycles and Political Consequences," *International Organization*, 38 (Winter), 1-40.

Dierickx, Ingemar and Karel Cool 1989: "Asset Stock Accumulation and Sustainability of Competitive Advantage," *Management Science*, 35 (December), 1504-1511.

Feenstra, Robert C., Tzu-Han Yang, and Gary G. Hamilton 1993: "Market Structure and International Trade: Business Groups in East Asia". NBER Working Paper #4536. Cambridge, Mass.: National Bureau of Economic Research.

Fields, Karl J. 1995: *Enterprise and the State in Korea and Taiwan*. Ithaca, N.Y.: Cornell University Press.

Flamm, Kenneth 1996: *Mismanaged Trade: Strategic Policy and the Semiconductor Industry*. Washington, D.C.: The Brookings Institution.

Fong, Glenn R. forthcoming: "Follower at the Frontier: International Competition and Japanese Industrial Policy," *International Studies Quarterly*.

Gerschenkron, Alexander 1962: *Economic backwardness in historical perspective, a book of essays*. Cambridge, Mass.: Belknap Press of Harvard University Press.

Hamilton, Gary G. and Nicole Woolsey Biggart 1988: "Market, Culture, and Authority: A Comparative Analysis of Management and Organization in the Far East," *American Journal of Sociology*, 94 Suppl., pp. S52-S94.

Hane, Gerald 1994: "The Real Lessons of Japanese Research Consortia," *Issues in Science and Technology*, 10 (WINTER), pp. 56-62.

Hart, Jeffrey A. and Aseem Prakash 1997: "Strategic Trade and Investment Policies: Implications for the Study of International Political Economy," *The World Economy*, 20 (July 1997), 457-476.

Hong, Sung Gul 1992: "Paths of Glory: Semiconductor Leapfrogging in Taiwan and South Korea," *Pacific Focus*, 7(1) (Spring 1992), 59-88.

Kim, Linsu 1997: "The Dynamics of Samsung's Technological Learning in Semiconductors," *California Management Review*, 39 (Spring), 86-100.

Klenow, Peter J. and Andrés Rodríguez-Clare 1997: "The Neoclassical Revival in Growth Economics: Has It Gone Too Far?" draft dated April 16, 1997, Graduate School of Business, University of Chicago (forthcoming in the 1997 NBER Macroeconomics Annual).

Krugman, Paul 1994: "The Myth of Asia's Miracle," *Foreign Affairs*, 73 (November/December), 62-78.

Lam, Danny K.K. and Ian Lee 1992: "Guerrilla Capitalism and the Limits of Statist Theory: Comparing the Chinese NICs," in Cal Clark and Steve Chan (eds.), *The Evolving Pacific Basin in the Global Political Economy* (Boulder, Colo.: Lynne Rienner Publishers), pp. 107-124.

Lau, Lawrence and Jong-Il Kim 1994: "The Sources of Growth of the East Asian Newly Industrialized Countries," *Journal of the Japanese and International Economies*, 8 (September), pp. 235-71.

Levy, Brian, and Wen-Jeng Kuo 1991: "The Strategic Orientations of Firms and the Performance of Korea and Taiwan in Frontier Industries," *World Development*, 19(4), pp. 363-74.

Mody, Ashoka 1990: "Institutions and Dynamic Comparative Advantage: The Electronics Industry in South Korea and Taiwan", *Cambridge Journal of Economics*, 14, 291-314.

Park, Yung Chul 1994: "Korea: Development and Structural Change of the Financial System", in Patrick and Park 1994, pp. 129-187.

Patrick, Hugh T. 1994: "Comparisons, Contrasts, and Implications", in Patrick and Park 1994, pp. 325-371.

Patrick, Hugh T. and Yung Chul Park (eds.), 1994: *The Financial Development of Japan, Korea, and Taiwan*. New York: Oxford University Press.

Stowsky, Jay 1992: "From Spin-Off to Spin-On: Redefining the Military's Role in American Technology Development," in Wayne Sandholtz, Michael Borrus, John Zysman, Ken Conca, Jay Stowsky, Steven Vogel, and Steve Weber, *The Highest Stakes: The Economic Foundations of the Next Security System*. New York: Oxford University Press.

Wade, Robert 1990: *Governing the Market: Economic Theory and the Role of Government in East Asian Industrialization*. (Princeton, N.J.: Princeton University Press), p. 270.

Weiss, Linda and John Mathews 1994: "Innovation Alliances in Taiwan," *Journal of Industry Studies*, 1 (December), pp. 91-101.

World Bank 1993: *The East Asian Miracle: Economic Growth and Public Policy*. New York: Oxford University Press.

Young, Alwyn 1994: "Lessons from the East Asian NICs: A Contrarian View," *European Economic Review Papers and Proceedings*, 38 (April), pp. 964-73.

Endnotes

1. The other team members are Michael Borrus and Tom Murtha. We have benefited greatly from the help and advice of David Mentley of Stanford Resources, Inc.
2. Hart and Prakash 1997.
3. Lau and Kim 1994, Young 1994.
4. Although a direct discussion of Krugman's claims and the underlying research are beyond the scope of this paper, it is worth noting that they depend critically on measurement choices and model specifications. For a recent rebuttal, see Klenow and Rodriguez-Clare (1997).
5. Cumings was using a metaphor developed earlier by Japanese political economists.
6. Borrus and Zysman are applying the resource-based view of the firm in a network setting. For an example of the literature at the firm level, see Dierickx and Cool 1989.
7. Borrus and Hart 1994.
8. Castellano 1997.
9. Castellano, op cit.
10. For example, a generation 3 substrate can produce six 12.1" displays, but only four of the 13.3". Producing the latter is feasible but possibly not economically justifiable as the primary output of the plant.
11. For an excellent discussion of this problem, see Flamm 1996.
12. A fourth *chaebol*, Daewoo, has investments in STN-LCD production. Daewoo has not invested in TFT-LCD production to date, but may invest in other advanced display technologies.
13. "South Korea, Taiwan Firms Raid Japanese Staffs, Buy Technology," *The Nikkei Weekly*, March 3, 1997, p. 20.

14. Cheonan is primarily associated with Samsung Display Devices. The original decision to shift TFT-LCD production to Samsung Electronics was based on the similarity to integrated circuit production plus the need to diversify away from a dependence on DRAM. Samsung Display Devices now wishes to diversify away from its CRT and STN-LCD business, so Samsung Electronics will loan its engineers and expertise to Samsung Display Devices until the plant at Cheonan is running successfully.
15. See the Samsung Electronics web site at <http://www.sec.samsung.com>.
16. "Samsung Introduces Thin TFT-LCD Monitors," Korea Herald, June 13, 1997.
17. "Samsung Electronics' TFT-LCD Produces First Annual Profit," Korea Economic Weekly, April 11, 1997.
18. The reorganization is described at LG Electronic's web site at <http://lge.expo.or.kr>. The other three SBUs are multimedia, living systems, and non-LCD displays.
19. Other LCD-related IC partners are Silicon Image and Vivid Semiconductor (both U.S. firms).
20. "South Korea, Taiwan Firms Raid Japanese Staffs, Buy Technology," The Nikkei Weekly, March 3, 1997, p. 20.
21. "LG Electronics to Supply \$1 Bil. Worth of TFT-LCDs to Compaq," Korea Economic Weekly, December 12, 1996.
22. "LG to Supply DEC with TFT-LCD Panels," Korea Economic Daily, May 10, 1996.
23. "LG to Export Notebooks to DEC on OEM Basis," Korea Herald, August 20, 1997.
24. "LG Semicon Invests 900 Bil. Won in TFT-LCD Manufacturing," Korea Economic Daily, March 15, 1997.
25. "Hyundai shuts U.S. display subsidiary," Electronic Engineering Times, November 24, 1997.
26. The line was ready for high-volume production by December 1995, but Hyundai postponed ramp-up until prices of 10.4" TFT-LCDs, which were falling rapidly at the time, stabilized. "South Korea Close to Production of Large LCDs," Dempa Shimbun via COMLINE, August 31, 1996, p. 1.
27. "HEI Invests Heavily to Raise TFT-LCD Output," Korea Economic Daily, June 2, 1997.
28. "Hyundai Electronics to Make Advanced LCDs for Toshiba," Nikkei Daily, October 24, 1996; and "Display Technology to Buy Hyundai Displays," Dempa Shimbun, via COMLINE, October 25, 1996.
29. The others included nuclear technology, civilian aerospace, semiconductors, computers, and environmental technology.
30. In 1995, it dealt with ocean technology; in 1996 with space technology.
31. Other industries in the promising/emerging category include: optical equipment, fine chemistry, new materials, genetics, aerospace/airplanes, environmental equipment, medical equipment, and control instrumentation.
32. MoST and MoTIE have been vying for dominance in the government's R&D budget in recent years. Prior to the 1990s, MoST was the main responsible agency for governmental R&D spending. By the end of 1996, MoST's budget (including \$1.25 billion out of total governmental R&D spending of around \$3 billion) was smaller than the combined budget of MoTIE and the Ministry of Information and Communications. Control is now shifting back to MoST as all R&D funding has to be approved by the MoST Minister under a recent law.
33. A fifth firm, Picvue, produces STN-LCDs, but has not indicated any interest in TFT-LCD technology and was not included in the study. The firm profiles that follow draw on interviews conducted in May 1997 as well as on information from English-language press reports and from Report #96.102 from the Asian Technology Information Program on the World Wide Web at <http://www.atip.or.jp>.
34. UMC is actually a minority owner of Unipac, but it is also the only investor to participate actively in Unipac's operations.
35. The HSIP is a government-funded initiative to encourage the development of high-technology industries. Firms locating there receive subsidies in the form of free or reduced rent and construction services, along with very attractive tax incentives. The land for the HSIP was initially owned by the Taiwanese armed forces, but the park is administered by Taiwan's National Science Council.

36. A majority of shares in Chiao Tung and several other government-owned banks have recently been sold to the public.
37. In the early 1990s, CPT considered adding another display technology -- plasma display panels -- which are suitable for larger applications, such as wall-hanging TVs. It had entered negotiations with an American company, Plasmaco. However, before licensing arrangements could be agreed on, Japan's Matsushita bought Plasmaco.
38. First International Computer (or *Ta Chong* in Mandarin), another member of the Formosa Plastics Group, is an important producer of notebook PCs, raising the possibility of coordination benefits similar to those that may be realized by the Korean *chaebol*. However, synergy did not appear to be a strong motivator for Nan Ya's investment.
39. "Taiwan Keeps Third Place as Information Product Supplier," China Economic News Service, September 15, 1997. The original source was the Market Intelligence Center, a government office.
40. "Notebook Computers: Top Firms Place OEM Orders Here," Business Taiwan, January 6, 1997.
41. "Taiwan to Boost LCD Production", Chinese Economic News Service, July 8, 1997.
42. "Development of Taiwan's Computer Industry," China News Agency, May 2, 1997.
43. One of our interviewees suggested a reason for the recent spate of announcements when he said that he would not want to be "either the first or the last" to negotiate a joint venture with a Japanese partner. His logic was that the first venture would be the most costly one for the Taiwanese partner, while subsequent ventures would be less expensive and therefore more financially viable. Now that CPT has paved the way, other firms may feel that it's safe to take the leap.
44. There is some doubt whether these investments, and similar announcements for the IC sector, will come to pass. Various news analyses have suggested at least two reasons that firms announce large high-tech investments even though plans are indefinite. One is to improve relations with the government, which is heavily promoting the high-tech sector. Another is to improve access to capital, because the local stock market generally rewards companies that make such announcements.
45. An excellent analysis of the changing relations between the state and industry can be found in Chu 1994.
46. For comparative purposes, it is interesting to note that ERSO began its LCD research two years after Samsung launched its LCD study group in Korea. Samsung turned out a 10.4" TFT-LCD in 1992, once again two years ahead of ERSO. From that point on, Samsung moved aggressively into high-volume production while ERSO's technology languished in search of a private sector champion.
47. Both technologies have been transferred to local firms -- the color filters to Asia Chemicals and the chip-on-glass to Wintek, a producer of small monochrome STN displays ("TFT-LCD Technology", ITRI Annual Report 1996).
48. Samsung Display Devices is also developing FED technology, "Samsung Display Sees Future in Batteries, PDPs, FEDs", Journal of the Electronics Industry, October 1997, via ATIP.
49. Weiss and Mathews 1994.
50. "Four Taiwan Firms Forge Alliance to Make TFT-LCD," Reuters Online, April 18, 1995.
51. Fong (forthcoming), Anchordoguy 1989, Stowsky 1992, Hane 1994.
52. Hong (1992) also relates firm structure to industry development in Taiwan and Korea, but for the case of semiconductors. Borrus (1988), Chapter 3, makes a similar analysis between the Japanese and U.S. chip sectors.
53. The smallest Japanese producer of notebook computer displays, Hosiden, had total revenues of more than three quarters of a billion dollars in the fiscal year ending March 1994, making it comparable in size to the Taiwanese firms.
54. Fields 1995, p.6.
55. World Bank 1993, pp.127-134.
56. See Patrick 1994, especially p.333.

57. Park 1994, pp.162-3; an explicit goal was the conscious replication of Japan's industrial structure.
58. Fields 1995, Table 4-5.
59. Park 1994, p.155. Financial liberalization has been advancing slowly in both countries. To the extent that Korean firms have both relied more heavily on the old system and are more concentrated, we would expect meaningful liberalization to proceed most slowly there due to corporate intervention in the political process. However, the currency crisis and IMF agreement occurring during the writing of this article may speed Korean reform.
60. Feenstra et al. 1993.
61. These are recent data from the government's Market Intelligence Center.
62. This contrast manifested itself previously for another capital-intensive electronic component - integrated circuits. In the early 1980s when Samsung began using licensed technology to produce memory chips, the sole Taiwanese IC producer was making application-specific chips that could be produced profitably on a smaller scale using simpler process technology. Taiwanese firms have only recently begun operating large-scale plants for the production of memory chips.
63. Gerschenkron 1962.
64. Hamilton and Biggart 1988, p. S84.
65. Wade 1990, p.270.
66. Hong (1992) points out that during the development of the semiconductor industry in Korea, the United States brought pressure to prevent direct government support for the industry, whereas, for a variety of reasons (pp.78-82), such pressure was not brought on Taiwan. This probably accounts for the initial differences in policy toward the display industry in each country, but, in Taiwan, the evolution of market structure we discuss prevented the government's direct involvement from achieving the same success as in the semiconductor case.
67. The Korea data come from Chen and Sewell 1996, Table 1, the Taiwan data from Taiwan Statistical Data Book 1994, Table 6-1, and the U.S. and Japan data from Business Times (Singapore), December 17, 1996, "Expenditure on R&D up 16.3%".
68. This point is similar to the analysis in Levy and Kuo 1991. See also Mody 1990.
69. Lam and Lee 1992.
70. Ibid., p. 108.
71. Statement by an IBM executive at an industry conference.
72. Hyundai could be considered an intermediate case, since it acted more cautiously than Samsung and LG and has entered into a complementary arrangement with Toshiba, a leading Japanese producer.
73. In fact, where learning by doing is important, technological gaps can multiply across sectors. Taiwanese firms were late entrants in the production of memory chips, a technology whose mastery appears to have facilitated Korea's entry into TFT-LCD production. Taiwan's younger memory producers are still focusing all available resources on expanding in advance of the next market upturn rather than diversifying into displays. Relative lack of experience in both memory chips and TFT-LCD is thus a double deficit for the Taiwanese.
74. We believe that identifying the Taiwanese competitive advantage with less-than-frontier technology is consistent with the claim of Levy and Kuo that Taiwanese firms, because of their small size, have less to lose and hence take greater risks and are more innovative (p.371 of Levy and Kuo 1991). Levy and Kuo define innovation as an effort "to develop new products or cost-reducing processes, to extensively differentiate existing products, *or to replicate with rapidity the efforts of other innovation-intensive firms*" (p.367, emphasis added), thus squarely confounding innovation and imitation.
75. "Acer counting on Shih's 'AcDonald' strategy," Straits Times, 7-13-92. While McDonalds is clearly an important model of effective operations management, it is not technologically innovative in the product-based sense used in this article.
76. "Acer Group: Marketing, Manufacturing In China," Dow Jones Business News, 5-30-96,