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FLYING GEESE AS MOVING TARGETS: ARE KOREA AND TAIWAN CATCHING UP WITH JAPAN IN ADVANCED DISPLAYS?

GREG LINDEN, JEFFREY HART, STEFANIE ANN LENWAY AND THOMAS P. MURTHA[1]

Can Asian second movers in high technology ever catch up with leading Japanese companies? Or does Japanese manufacturing advantage confine later entrants to second tier supplier roles? Do Asian companies continue to take cues from their governments about strategies? Or do companies identify their own market opportunities, devising strategies to leverage country- and firm-specific capabilities without paying much attention to governments?

This paper examines strategies that Korean and Taiwanese firms and governments adopted to build globally competitive advanced display manufacturing capabilities. We selected these two countries because observers often single them out among newly industrializing countries (NICs) as exemplars of industrial development. Firms from both countries entered the flat panel display (FPD) industry after Japan-based producers established world market dominance.

We assessed case evidence from two perspectives: Asia scepticism and network globalization. Sceptics predict that Asian NICs will fail to achieve the wealth of the advanced countries, but will remain locked in a regional production hierarchy that Japan leads. Globalization researchers argue that East Asian production networks show increasing pluralism, and often cite evidence of interpenetration by US firms' affiliates, alliances and supply relationships.

Economists in the sceptics' camp have used aggregate data to support the idea that resource mobilization has driven Asian NICs' growth, rather than technology or productivity improvements. Resources face natural limitations. But technological and productivity advances can theoretically increase without limit (Lau and Kim 1994; Young 1994). As a consequence, Krugman argued (1994), NICs will face persistent "technological gaps" relative to wealthier countries.[2]

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Political scientists have arrived by a different route at similar conclusions. In 1984 Cumings re-introduced the "flying geese"[3] analogy of East Asian development in which technology diffuses from Japan to close follower countries and then to their followers. This trajectory culminates in convergence, as follower countries take over industries and export back to the leaders. Ultimately the followers become leaders when they originate new industries themselves. Bernard and Ravenhill (1995) more recently argued that convergence will not necessarily occur, in part because complex production networks link countries in a Japan-dominated supply architecture.[4] Although the networks transcend national boundaries, they are built on country- and firm-specific knowledge and capabilities that do not as readily diffuse.[5] Continuous innovation keeps Japanese companies in the lead. They retain discretion over knowledge flows and network operations, and pursue export strategies that disproportionately direct output to third countries, particularly the US.

Proponents of the network globalization perspective argue that the globalization of firms' strategies has brought to a close East Asia's era as a Japanese preserve. Borrus (1994), for example, described collaboration between American electronics firms and Asian producers who developed specializations in a regional supply architecture. Borrus and Zysman (1997) explained firms' discretion within cross-national production networks as a function of "Wintelism". In their Wintelist scenario, any firm from any country can gain a disproportionate share of rents compared to other network participants, provided it controls difficult-to-imitate assets such as brand names, product-specific distribution networks, specialized knowledge or innovative capabilities.[6] This perspective highlights firms' resources and strategic choices in preference to country and interregional phenomena. In principle, Wintelism throws network power up for grabs.

We have organized the article as follows. First, we discuss strategic issues that managers must address in FPD market entry decisions. Next, we present case studies based on interviews at Korean and Taiwanese FPD firms and government agencies. We then compare business-government strategic interaction in the Korean and Taiwanese FPD industries. We move on to analyze competitive strategies the firms adopted to close the technological gap with Japan, and discuss how firm differences determined their relative strengths in their respective networks. We conclude by discussing the implications of our analysis for Asian economic growth potential.

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2 Detailed discussion of these findings is beyond this paper's scope. But it is worth noting that they depend critically on measurement choices and model specifications. Klenow and Rodriguez-Clare (1997) offer a rebuttal.

3 Bernard and Ravenhill (1995) summarize Akamatsu Kaname's original analogy of the 1930s (p. 172).

4 The "supply architecture" idea first appeared in a 1992 study of the FPD industry by Borrus and Hart (1994).

5 Bruce Kogut has written extensively with various collaborators on the diffusion of country-specific capabilities within and across national borders (e.g. 1993). He argues that cross-border diffusion considerably lags diffusion within countries, creating long cycles of wealth creation centered on particular countries.

6 Business strategy researchers, particularly proponents of "the resource-based view of the firm" (see Dierickx and Cool 1989) have in recent years contributed extensively to the growing literature on firm-specific advantage.

TABLE 1: GENERATIONS OF TFT-LCD AND STN-LCD MANUFACTURING EQUIPMENT

Generation	Typical substrate size	Optimized for display size (qty)	Earliest adoption (adopter)
1	300 mm × 400 mm	8.4″ (4)	1991 (Sharp)
2	350 mm × 450 mm	10.4″ (4)	1994 (Sharp/Hosiden)
3	550 mm × 650 mm	12.1″ (6)	1996 (DTI)
3.5	600 mm × 720 mm	13.3″ (6)	1997/98 (Samsung)

Sources: Business press and interview materials.

TFT-LCD MANUFACTURING

Thin film transistor liquid crystal display (TFT-LCD)[7] technology poses exceptional challenges and risks to manufacturers. Current TFT-LCD fabrication plants (generation 3; see Table 1) require an initial capital investment of at least $500 million. New entrants attain satisfactory yields with great difficulty and additional expense. Among many thousands of transistors deposited on each glass substrate, just a few defects render a display unusable.

In 1992, Sharp undertook the first high volume production of notebook-computer-size TFTs, measuring 8.4″ diagonally. Since then, notebook screen sizes have increased at a pace that far outstripped industry expectations. Some early entrants moved quickly to establish plants to make larger screen sizes, and surprised the industry by promptly achieving commercial yields. The first displays gave way to 9.5″ displays, then 10.4″ in rapid succession. In 1995, 11.3″ caught on. But before this size could gain a dominant market share, 12.1″ superseded it in 1996. In 1997 13.3″ and 14.1″ gained currency, as next generation (3.5) factories came on-line. Consumers have demanded even larger sizes as LCDs penetrate the desktop monitor market.

Firms that successfully adopted advanced generation tool configurations left some competitors temporarily behind. Long investment and equipment order lead times locked many into inefficient facilities. In Korea, for example, Samsung responded to changing demand patterns by converting a second-generation 10.4″ plant to produce 12.1″ displays, cutting productivity by half. Particularly in Taiwan, some firms delayed investments to wait out the market.

Learning economies and process improvements have so far led prices for given display sizes to decline over time, just as they did for integrated circuits. Integrated

7 Liquid crystal contains slender elongated molecules that can orient along electric field lines to permit light transmission. In TFT-LCDs, each display pixel has a transistor or diode. Each transistor acts, in effect, as a switch that, turned rapidly on or off, polarizes the liquid crystal to block light or allow it to pass.

circuits (ICs) have always declined in size as manufacturers sought to increase yields per silicon wafer. Each generation has required new equipment that produces at finer tolerances. TFT-LCD manufacturing in some respects inverted this phenomenon. As manufacturers sought larger panel sizes and/or more finished panels per glass substrate, they required new equipment to handle larger substrates.[8]

TFT-LCD production technology bears many similarities to IC processes. Both require clean rooms, photo-lithography, chemical and physical vapor deposition (CVD, PVD), and advanced testing. Clean room operators require extensive training. Errors at any process step can produce faulty devices. After factories attain commercial yields, large production engineering teams remain on hand to troubleshoot and guide process improvement.

TFT-LCD producers can rely on outside suppliers for many key inputs. But doing so can expose producers to the risk of market shortfalls leading to output curtailments. For example, color filters, driver chips, and backlights, which account for between 5 and 15 percent of the variable cost of a display, have all experienced periodic shortfalls. Some of the firms in our case studies have initiated internal production to ensure reliable supplies.

The interaction of TFT-LCD supply and demand exhibits cyclicality that many observers have compared to historical patterns in the memory chip market. But the underlying causes do not entirely correspond. Similarities include the trend toward ever larger, lumpy capital requirements such that any new plant creates a sizeable addition to world output (see Flamm 1996). But many TFT producers have also seriously misforecasted new plant ramp-up times as well as demand transitions as preferences evolved in final goods markets. Resulting difficulties in timing investments have contributed to alternating periods of shortage and oversupply. Shortages create high prices, tempting new firms to enter the industry. New investments can lead to temporary oversupply and price erosion. In 1995–96, for example, Korean producers' new, unexpected investments drove world 10.4″ prices from around $1,500 to below $500 for a time. Firms in Taiwan and the United States reconsidered their investment plans. When demand shifted toward 12.1″ displays in mid-1996, shortages emerged and then intensified as many producers began cutting two 12.1″ displays from substrates that previously produced four 10.4″ displays.

The firms in our study experienced different effects from cyclical market changes and responded with different strategies. In Korea, the three leading firms invested heavily in TFT-LCD production. In Taiwan, periodic declines in the market have delayed production plans.

THE ADVANCED DISPLAY INDUSTRY IN KOREA

The main actors in the Korean display industry are three of the big-four *chaebol*[9] firms, Samsung, Hyundai, and LG (formerly Lucky Goldstar), and the major govern-

8 For example, generation 3 substrates can yield six 12.1″ displays, but only four 13.3″. The latter specification, though feasible, would reduce productivity.

9 Korean *chaebols* resemble (with important differences) Japanese *keiretsu*, large, diversified networks of firms sharing financial and supply relationships. The *chaebols* grew to their present size in the period of Korea's heavy industrialization. For a discussion, see Lee (1997). Daewoo, the fourth largest *chaebol*, has so far invested in less advanced STN-LCD production, but not in TFT-LCDs. It may yet invest in other advanced display technologies.

ment ministries charged with supporting technological innovation, the Ministries of Trade, Industry, and Energy (MoTIE) and of Science and Technology (MoST). The *chaebols* made their investments without government direction. The government-mandated financial intermediation system in Korea, however, encourages banks to flexibly review business cases underlying *chaebols'* capital requests. Even though the government did not formally target the FPD industry, the preferential financial environment may have helped the firms to more quickly mobilize the large sums needed to build manufacturing facilities. But the decision to invest rested with managers who believed that FPD manufacturing provided a necessary basis for future profitability in advanced electronics.

Samsung, LG, and Hyundai all invested heavily in equipment and engineering expertise from Japan. They also collaborated with US firms and devoted substantial internal resources to incremental equipment improvements, developing internal process expertise and creating new process designs. Once the firms had established production, Korean government officials perceived a need to reduce dependence on Japanese production tools. They charged the Electronic Display Industry Research Association of Korea (EDIRAK)[10] in 1995 with developing a program to encourage the growth of a Korean materials and equipment supply base. Thus far, direct government impact on the industry remains modest.

The chaebols decide to invest in TFT-LCD production

In February 1995 Samsung invested in Generation 2 technology to establish the first high-volume production facility in Korea. Using an aggressive forward-pricing strategy, the company began to win market share away from producers in Japan late in the year. LG and Hyundai proceeded less aggressively. By 1997, these firms had also established themselves as global competitors, and the three firms had each invested over $1 billion. When 12.1" demand accelerated in 1996–97, the companies began to reap the benefits of managements' decisions.

Samsung. Samsung Display Devices (SDD; 1995 revenues: $2.3 billion) is an affiliate of Samsung Electronics (1995 revenues: $19.4 billion). Both are members of the Samsung Group (1995 revenues: $25 billion). SDD created a TFT-LCD research group in 1984, and subsequently licensed technology from Optical Imaging Systems (OIS) in the US. The company enhanced its abilities to absorb and improve upon advanced FPD technology by hiring researchers away from Japanese labs.[11] By 1998, Samsung Electronics had become the world's fourth largest producer of notebook displays behind DTI, Sharp, and NEC (DisplaySearch 1998).

Although the Samsung Group has evolved into a giant conglomerate, it retains vestiges of its roots as a family-run company. The decision to make the costly move from R&D to mass production was taken at the apex of the group hierarchy, with

10 First established in 1990 as an association of government, academic and industry researchers. Earliest activities pertained to traditional Cathode Ray Tube (CRT) display manufacturing standards.

11 "South Korea, Taiwan Firms Raid Japanese Staffs, Buy Technology", *Nikkei Weekly*, March 3, 1997, p. 20.

vital support from Kun-Hee Lee, Group Chairman and son of the founder as well as from Kwangho Kim, Vice Chairman and President of Samsung Electronics.

SDD's investment criteria for TFTs weighed strategic importance more heavily than near-term profitability. TFT manufacturing offered Samsung the opportunity to diversify away from the cyclical DRAM business while at the same time leveraging its DRAM manufacturing expertise. The investments also assured the group of a steady supply of state-of-the-art display components for a wide variety of electronic products and multimedia applications. Pride and a sense of rivalry with Japan may also have played a role. Samsung's managers believed that Japanese industry observers did not take Korean companies seriously as manufacturing challengers in TFT-LCDs.

In January 1991, the TFT-LCD business moved to Samsung Electronics' semiconductor group to take advantage of similarities in process technology and engineering know-how. SDD retained the less-demanding passive matrix STN-LCD business.[12] Samsung Electronics completed a pilot plant using 300 mm × 300 mm (sub-generation 1) substrates in Kiheung in 1991. The following year it developed a prototype 10.4″ VGA[13] display for two-at-a-time ("2-up") production on 300 mm × 400 mm substrates. The subsequent pilot line began processing 2,400 substrates per month in September 1993, sold primarily to external customers. Samsung started a generation 2, high-volume production facility ("line 1") late in 1993 at Kiheung to process 370 mm × 470 mm substrates. Full-scale production began in February 1995. By July, the line had ramped up to 20,000 substrates per month. Each substrate yielded up to four 10.4″ VGA displays for an annual plant capacity of about one million displays. Samsung entered a cross-licensing agreement with another late entrant in 1995, the Japanese firm Fujitsu. Fujitsu provided wide viewing-angle technology in exchange for Samsung's high-aperture-ratio technology.[14]

In April 1996, Samsung invested in a 1.5 million annual capacity generation 3 facility in Kiheung to produce 12.1″ SVGA displays on 550 mm × 660 mm substrates. The plant cost between $600 and $800 million, mainly for Japanese production equipment. In 1998, Samsung expected the facility to achieve an 80 percent yield processing 6-up 12.1″ displays from 25,000 substrates. Line 1 converted to 2-up 12.1″ production in 1996. On February 21, 1998, following rumors of a delay,[15] Samsung announced the opening of the world's first generation 3.5 line at Chunan,[16] producing 13.3″ XGA and 17.0″ SXGA displays on 600 mm × 720 mm substrates.

12 Passive matrix LCDs use row and column driver chips to apply an electrical current to the row electrode strip while applying appropriate voltage to each pixel on the column electrode strip. This technology helped to commercialize LCDs for laptop computers. But the displays respond much more slowly and with less clarity than do (active matrix) TFT-LCDs. STN facilities cost about half as much as TFT plants to build. But as TFT-LCD prices continue to decline, they have supplanted STNs in many low priced notebooks.

13 VGA or video graphics array refers to the graphic system developed for the IBM PC/AT to control display resolution. VGA display resolution is 640 × 400 pixels. SVGA or super VGA is 800 × 600. XVGA or extended graphics array has a resolution of 1024 × 768 (Yamazaki *et al.* 1996: 7).

14 Wider viewing angles will help TFTs compete with CRTs for the desktop market. As aperture ratios increase, displays gain in brightness for given levels of power consumption.

15 "Glutted Markets Convince Korean Makers to Delay Expansion", *Korea Economic Daily*, February 16, 1998.

16 Chunan is primarily an SDD site. SDD will borrow engineers and expertise from Samsung Electronics in a strategy to diversify away from its CRT and STN-LCD businesses.

TABLE 2: TFT CAPACITY BY COMPANY: 1ST QUARTER 1998 AND 4TH QUARTER 1999

Company	Percent capacity share 1st quarter 1998 (12.1″ equivalents)	Projected percent capacity share 4th quarter 1999 (13.3″ equivalents)
DTI	17.5	13.0
Sharp	17.4	11.8
NEC	13.0	10.1
Samsung	12.3	11.1
ADI	8.0	3.7
Fujitsu	7.1	3.2
LG	6.5	12.8
Hitachi	7.0	9.8
Matsushita	3.7	5.5
Hosiden-Philips FPD	2.4	3.4
Hyundai	1.9	2.7
Sanyo	0.4	5.2
Other	2.9	7.8

Source: DisplaySearch (1998).

Although largely dependent on foreign production equipment sources, Samsung leveraged internal capabilities to meet intermediate input needs. In late 1996, Samsung Corning, a joint venture with the US glass giant, began processing the fusion glass used for substrates. Samsung Aerospace was bidding to supply lithography equipment. SDD will begin manufacturing color filters for a large proportion of Samsung TFT-LCDs by the end of 1998. Samsung Electronics provides the driver chips.

As the largest seller of computers in Korea and one of the top ten sellers in Asia, Samsung enjoys strong prospects for downstream integration. In 1996, it also purchased AST Research, an ailing US desktop and notebook PC maker. In June 1997, the company announced a 14″ XGA FPD desktop monitor, although it did not anticipate a major market for such products until 1999.[17] Currently, Samsung's PC division sources all of its displays internally.

Samsung's overall FPD strategy envisions strategic alliances with a few select companies producing a full range of sizes, and leveraging internal infrastructure. Management intends to emphasize process innovation in Samsung's bid to become a top global supplier. Samsung has also aggressively pursued leading edge laptop computer and monitor markets. The latter may have a far greater potential. Chunan is optimized for desktop monitors. Based on investments and announcements to date, Samsung currently holds 12.3 percent of global TFT capacity, declining to 11.1 percent by the end of 1999 (DisplaySearch 1998; see Table 2).

17 "Samsung Introduces Thin TFT-LCD Monitors", *Korea Herald*, June 13, 1997.

LG. LG Electronics (1995 revenues: about $8.5 billion), is part of the LG Business Group. The LG Group's electronics affiliates are about half the size and much less vertically integrated than those of Samsung. When management initially considered high-volume TFT production, uncertain future demand precluded a decision based on strict financial analysis. But top management believed that portability would strongly influence the degree of market penetration for multimedia products, to which LG had committed strongly. Management also hoped to reduce LG's dependence on Japanese component sources. Specialized motor and chip shortages had at times disrupted LG's advanced VCR production lines. Management regarded five years of losses as a reasonable premium against future TFT supply problems.

Research began at LG Electronics in 1987. By 1989, the teams demonstrated their first working device. In 1990, an R&D center was established at Anyang. About 250 employees continue to operate that pilot line to process about 12,000 substrates annually for 10.4″ SVGA and 12.1″ SVGA displays. In 1993, LG broke ground for a $600 million production facility at Kumi, one of Korea's "science parks". In 1994, the new line began processing 10,000 370 mm × 470 mm substrates (second generation) monthly. By June 1996, the line was producing 1.8 million 10.4″ display-equivalents per year with about 1,400 workers. The plant expanded to its monthly capacity of 40,000 by the end of the year.

In 1996, LG installed a second line at Kumi using generation 3 technology. Line 2 began operating in late 1997. It could eventually process up to 40,000 substrates per month, the equivalent of over 2 million 12.1″ displays per year. Although planned for 550 mm × 650 mm substrates, the line was respecified to handle 590 mm × 670 mm for larger displays. The new facility will also manufacture color filters, replacing current imports from Japan that have proven subject to periodic shortages. Another group member, LG Semicon, serves as main source for driver ICs.[18] Other group members have developed materials such as color resist and backlights.

In 1994, LG entered a $30 million joint venture with Alps Electric, a Japanese components firm, to develop ultra-clean manufacturing technology at Alps Central Laboratory in Japan. Alps began the research jointly with a nearby university in 1988, but experienced financial difficulties. When Japanese firms declined to join the effort, Alps turned to LG. LG plans to implement the technology for the first time on line 2.[19]

LG entered another joint development project, including equity, with Photon Dynamics, a US test equipment producer. Photon Dynamics leads in developing equipment to test individual TFT-LCD pixels at intermediate manufacturing process stages. The project proved crucial to LG's zero-defect objective,[20] and helped LG gain a five-year, $1 billion contract to supply 12.1″ and larger displays to Compaq, despite having only one year of volume production experience.[21]

TFT-LCD production helped improve LG's position in downstream markets. In May 1996, LG established a strategic alliance with Digital Equipment Corporation (DEC) in the US. LG supplies 11.3″ and 12.1″ FPDs for jointly developed notebooks that DEC

18 Other LCD-related IC partners are the US firms Silicon Image and Vivid Semiconductor.

19 "South Korea, Taiwan Firms Raid Japanese Staffs, Buy Technology", *Nikkei Weekly*, March 3, 1997, p. 20.

20 *De facto* industry standards permit shipping goods with as many as five defective pixels.

21 "LG to Supply $1 Bil. Worth of TFT-LCDs to Compaq", *Korea Economic Weekly*, December 12, 1996.

markets.[22] Designs, including one version featuring an extremely thin display, were completed in August, 1997. LG began to assemble and ship 10,000 notebooks to DEC monthly. The arrangement replaced DEC's prior deal with Citizen Watch Company of Japan.[23]

LG has pursued an aggressive technology strategy, far more open to strategic alliances by comparison to Samsung. The company has restricted vertical integration to drive electronics, color filters, and backlights, while searching for partners who can provide cost or product differentiation advantages. Management believes that the industry is young, and that competitors will need alliances to stay ahead of technology changes and final product demand. DisplaySearch (1998) expects LG's global share of capacity to grow from 6.5 percent to a second ranking 12.8 percent between early 1998 and end-year 1999 (see Table 2).

Hyundai. Hyundai Electronics Industries (HEI; 1995 revenues: $5 billion) belongs to the Hyundai Group (1995 revenues: $75 billion). HEI Chairman Mong-Hun Chung made the original investment decision. Chung wanted to end reliance on outside display suppliers for Hyundai's growing multimedia business. He was willing to locate HEI's production anywhere in the world.

In 1992, HEI began working with Alphasil, a small US TFT-LCD firm, and its co-founder Scott Holmberg. Honeywell, the company's previous corporate sponsor, had abandoned it. HEI's management was impressed with Holmberg's progress toward establishing a pilot line with little capital. Chairman Chung sent an engineering team to California to work with Holmberg. The project became Hyundai's line 1, producing specialized displays for aircraft and military use. Hyundai established a new firm, ImageQuest, as a subsidiary with Holmberg in charge. Hyundai invested $40 million to complete the line. Hyundai made the investment as part of a broad effort to internationalize its activities. Hyundai learned much about TFT-LCD technology through ImageQuest. Management decided, however, that the mostly US equipment on the line worked well for R&D, but would not work for high-volume production. ImageQuest closed in November 1997. It had "fulfilled its business mission", a company spokesperson said.[24]

In late 1993, Hyundai broke ground at Ichon for a facility capable of 4-up production of 10.4″ displays on 370 mm × 470 mm substrates (generation 2). High volume production began in mid-1996.[25] HEI planned Line 2 to process 20,000 substrates per month, but it has not operated much above 12,000. The company announced plans for a second Ichon plant in June 1996, and broke ground in March 1997. The plant was to feature a 35,000 substrate-per-month generation 3 line, cutting 550 mm × 650 mm glass into six 12.1″ displays. Demand shifted rapidly, however, and Hyundai added a 5,000 substrate per month line in its existing plant to produce 12.1″ displays. The company then upgraded the line under construction to handle

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 "Hyundai shuts U.S. display subsidiary", *Electronic Engineering Times*, November 24, 1997.

25 The line was ready by December, 1995. Hyundai postponed ramp-up until falling 10.4" prices stabilized. ("South Korea Close to Production of Large LCDs", *Dempa Shimbun* via COMLINE, Aug. 31, 1996, p. 1.)

600 mm × 720 mm substrates for 6-up 13.3″ production.[26] If completed in 1998, the plant will cost an estimated $600 million, a down payment on the five-year, $1.8 billion TFT-LCD investment plan Hyundai announced in June 1997. Most of the line 2 equipment was Japanese, with the notable exception of CVD equipment by dominant supplier Applied Komatsu Technologies (1996 global CVD market share: 80 percent). AKT, a joint venture between Applied Materials of the US and Komatsu of Japan, manufactures in Santa Clara, California.

Despite its latecomer status, Hyundai received a vote of confidence from Toshiba in late 1996: a contract to purchase 10,000 12.1″ displays per month. Toshiba will transfer its designs (via mask sets) to Hyundai, which had previously licensed Toshiba technology.[27]

Hyundai initially adopted the most global strategy among the Korean TFT manufacturers. But the ImageQuest experience, plus previous difficulties with US-built semiconductor equipment, turned the company back toward an Asian equipment supply base. Persuaded that US tools were suited primarily for low-volume production,[28] Hyundai did not leverage ImageQuest's process experience in its high-volume plants in Korea. As a consequence, after the company turned to Japan for equipment and expertise, it was slow to raise yields to competitive levels. DisplaySearch predicts Hyundai will hold 2.7 percent of global capacity in 1999, compared with 1.9 percent in early 1998 (see Table 2).

The role of government policy in the Korean display industry

The Korean government did not directly support Korean *chaebols'* entry into the TFT-LCD market, although in general the giant firms enjoyed preferential treatment in the Korean financial system. Government funds may have modestly facilitated entry by subsidizing science parks like Kumi or funding training programs for LCD engineers. In 1991, MoTIE launched a $6.4 million program for notebook display development, leading to the creation of a 10″ module in 1994. All of the Big Four participated. Although the four agreed to cross-licensing, they declined to invest in a joint venture to produce displays. The *chaebols* preferred to individually invest, contradicting government guidance.

In the mid-1990s, the government shifted its attention from display manufacturing to display equipment. Officials hoped to reduce balance-of-payments pressures from Japanese equipment imports. The firms' dependence on Japanese equipment also aroused insecurities born of historic enmity. Two major funding efforts addressed these issues, a program in the G-7 Han Project[29] in 1995, and a program proposed in October 1996 by MoST. Funding was ultimately consolidated in the Electronic Display Industry Research Association of Korea (EDIRAK).

26 "HEI Invests Heavily to Raise TFT-LCD Output", *Korea Economic Daily*, June 2, 1997.

27 "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.

28 Indeed, even by 1998 few US tool makers had tested their equipment in high volume settings, which existed only outside of the United States.

29 G-7 Han is an intergovernmental, multiprogram initiative to diversify Korea's sources of technology imports and bring national technology development into line with the Group of 7 leading industrialized countries.

Government officials interested in economic development generally split along ministerial lines in their opinions about strategies for competing with Japan. MoST officials generally agreed that the bureaucracy should not micro-manage private firm decision-making. Realistically, these officials pointed out, the *chaebols'* growing economic power insulated their internal decision processes from top-down government direction. MoST officials argued that strategy should focus on generic technologies and education in order to remove systemic roadblocks to innovation and avoid insulating *chaebol* managers from market incentives. Most MoTIE officials disagreed, arguing that government should target specific industries to enhance Korean firms' international competitiveness and to reverse growing trade deficits, especially with Japan.[30] Rising manufacturing materials costs and wage pressures from low unemployment were diminishing Korean competitiveness in international markets. This trend has since reversed.

EDIRAK officials have invested moral suasion but few funds to arouse shared concern among member FPD firms about dependence on Japanese equipment. The firms spent over $800 million on Japanese tools in 1996. EDIRAK officials perceived these imports as significant contributors to balance-of-payments pressures with Japan. The group proposed a program of cooperation with a counterpart US organization, the United States Display Consortium (USDC) as a way of building relationships between Korean manufacturers and US equipment suppliers.

This program has proven difficult to implement. Most EDIRAK member firms had enjoyed long, successful relationships with Japanese counterparts. Their managers were not comfortable abandoning these relationships to work with US firms that lacked high volume production track records. The Koreans expected this lack of experience to translate directly into lower yields as well as diminished up-time on their lines. Official financing for proposed trials may not be sufficient to overcome this reluctance in the near term, given the Korean firms' strategic objective to wrest market share from FPD makers located in Japan soon.

Despite the scepticism of the Korean firms, market access and the opportunity to gain experience with high volume manufacturers offered a strong incentive to US firms to pursue EDIRAK/USDC joint-funded projects. The two organizations signed a memorandum of understanding negotiated during the first nine months of 1996. Twenty-three members of USDC visited Korea in October 1996 to discuss possible collaborations. Proposals for the first round of projects were due in April 1997. Two projects were announced in January 1998, with financing provided by EDIRAK and the American firms, MRS (steppers) and Accudyne (cell assembly).[31]

EDIRAK may significantly contribute to the Korean TFT-LCD infrastructure. But the Asian economic crisis in late 1997–98 added uncertainty to the future of the USDC–EDIRAK joint development projects. Financial pressures resulting from the *won* depreciation may have diminished Korean firms' flexibility to introduce untried equipment. In addition, Japanese manufacturers assert and Korean customers

30 MoST and MoTIE have vied for budgetary dominance. Prior to the 1990s, MoST held main responsibility for government R&D spending, but control gradually shifted to the Ministry of Information and Communications and MoTIE. Recent legislation shifted the balance back, requiring the MoST minister's approval for all R&D funding.

31 "Korea–US Partnership to Develop Core Equipment for TFT-LCDs", *Korea Economic Daily*, January 12, 1998.

agree that they have sustained a free, steady trade in state-of-the-art equipment, despite Korean government concerns to the contrary. We regard these claims as credible, particularly in light of the challenges all FPD tool makers have experienced recovering development costs in the face of rapid changes in substrate sizes.

THE ADVANCED DISPLAY INDUSTRY IN TAIWAN

The Taiwanese story contrasts sharply with that of Korea. As of Autumn, 1997, Taiwanese firms were not engaged in high-volume production of notebook-size TFT-LCDs. Two firms, Unipac and Prime View, produced smaller TFT-LCDs and planned to produce larger displays. Chung Hua Picture Tubes produced STN-LCDs and had entered a TFT production alliance with ADI, a joint venture of Mitsubishi Electronics and Asahi Glass. Another STN producer, Nan Ya, was negotiating with Japanese producers to license TFT technology.[32]

Taiwan's government has entrusted significant human, financial, and physical resources for promoting technology to a single government agency, the Industrial Technology Research Institute (ITRI). ITRI's microelectronics research laboratory, the Electronics Research and Service Organization (ERSO), hires top engineers to set up pilot facilities that often evolve into full-scale factories. Because it often commercializes technologies it develops, private firms sometimes regard ERSO as a competitor rather than a supporter.

Taiwanese companies are generally much smaller than their Korean counterparts. Bankers rigorously evaluate new projects, contributing to relatively conservative capital budgeting norms. As a partial consequence, Taiwan's banking system remained relatively unscathed in the wake of the 1997 Asian economic crisis. The atomized Taiwanese industrial structure, however, precluded the creation of government-supported production consortia and has also inhibited individual firms from accumulating the capital needed to build TFT-LCD plants. This may have slowed the Taiwanese industry's development, but companies may also have benefited by avoiding misplacing their bets. Recently delayed capacity increases in Korea may raise the priority of domestic manufacturing in Taiwan. According to Korean informants, Taiwanese notebook assembly companies receive low priority in display shortages because of their small size. Yet Taiwan's global dominance in assembly depends in part on availability of these components.

Unipac. Unipac Optoelectronics opened the first volume production facility for TFT-LCDs in 1994. Unipac is affiliated with United Microelectronics Corporation (UMC), which ERSO spun off in 1980 as Taiwan's first private IC producer. UMC sales grew from nearly $400 million in 1993 to $950 million in 1995. Other Unipac investors include several venture capital funds and the China Development Corporation, investment arm of the Kuomintang (KMT), Taiwan's dominant political party.

32 Picvue also produces STNs, but has not indicated any interest in TFTs and was not included in the study. Teco, a large electrical and electronics producer and Chi Mei, a large petrochemicals firm, have TFT investment plans. The firms have not announced details nor technology partners, so these plans are difficult to assess. The firm profiles that follow draw on interviews conducted in May 1997, English-language press reports and Report #96.102 from the Asian Technology Information Program on the World Wide Web at http://www.atip.or.jp.

The corporation owns shares in many high-technology enterprises. Only UMC, which owns 13 percent, has seconded employees to the venture.

Unipac was founded in 1990 to make sensors for fax machines. The fax industry failed to develop in Taiwan, however, and Unipac turned to TFT-LCD production. Unipac foresaw strong domestic demand from Taiwan's growing notebook assemblers. The explosive growth of TFT manufacturing in Japan created positive expectations for the industry's potential in Taiwan.

The company adopted a strategy of learning-by-doing, starting with small displays. Volume production of 4″ screens for hand-held TVs and other portable applications began in 1994 on a generation 1 line at a rate of 2,500 300 mm × 400 mm substrates per month. Unipac located the line in the Hsinchu Science-Based Industrial Park (HSIP), clustered with most other high technology electronics producers in Taiwan. The line cost only $80 million to build.[33]

Unipac added a 5.6″ module line in 1996 and expanded to 6,250 substrates per month. By mid-1995, Unipac had created prototypes of 10.4″ displays and planned to produce in volume by 1997. But when 10.4″ displays declined precipitously, the company postponed its investment. Unipac has continued to adjust its plans as the market changed. In 1997, the company expected to begin volume production of 12.1″ SVGA modules in 1998.

Unipac recently diversified its display portfolio by agreeing to subcontract as a foundry for PixTech, of France. PixTech has developed displays using an alternative technology known as field emissions (FED). TFT-LCD and FED share several common technologies: thin film deposition, photolithography, driver attachment, and driver circuits. Unipac will undertake FED production in a facility vacated by UMC, which has made a $5 million investment in PixTech.

Kopin, a US company, has also signed a sourcing agreement with Unipac. Unipac will manufacture Kopin's micro-display, primarily used in portable products and video glasses. The technology suits the UMC–Unipac combination well. It requires an initial production stage in a silicon wafer foundry and a second stage transferring the circuit from the silicon wafer to a glass substrate. UMC also invested in Kopin.

Prime View International. Prime View International (PVI) started up in 1992 with an idea for reducing the number of driver ICs used in TFT-LCD module production. The four founders believed this innovation could reduce module production costs by 10–15 percent. In order to prove the concept's feasibility, they borrowed an existing pilot line at ERSO. Armed with positive results, the founders obtained majority financial participation from Yuen Foong Yu (YFY), Taiwan's largest producer of paper products (1995 revenues: about $800 million). YFY management wished to diversify into high technology. Chiao Tung Bank, which the government has used for venture capital investments and loans to strategic industries, took a minority position.[34]

33 The HSIP is a government initiative to encourage high-technology industrial development. Firms there receive subsidized rent and construction services, along with tax incentives. The armed forces originally owned the land but the park is administered by the National Science Council.

34 The majority of Chiao Tung shares and of several other state-owned banks were recently sold to the public.

PVI began construction of its HSIP plant in October, 1994. By late 1996, the company had spent about $140 million on the plant and a generation 2 line with a monthly capacity of 6,000 370 mm × 470 mm substrates. Japanese production equipment dominated. PVI christened its line with a 5″ module produced 15-up, suitable for small TVs and arcade games. PVI initially sold about half of its output in Taiwan. Sales to Japan were building slowly as the company worked through Japanese buyers' lengthy qualifying processes. Recently PVI added 1.8″ and 2.5″ extra-high-resolution displays for camcorders and digital cameras, as well as a 6.4″ format. Although the company announced a plan to begin sampling 12.1″ displays by the end of 1997, production capacity remained unchanged when this article was written. PVI managers have hesitated to enter notebook display production in part due to concerns about how long generation 3 will persist as the dominant format.

Prime View enjoys a reputation as an innovative firm. In addition to its original international patents, its engineers have developed a proprietary manufacturing process, backlight (outsourced locally), and chip-on-glass technique to reduce the module size of smaller displays.

CPT. Chung Hwa Picture Tubes (CPT), a majority-owned affiliate of Tatung, only recently began building a high volume TFT-LCD facility. Tatung, one of Taiwan's older consumer electronics manufacturers, sold over $1.5 billion in goods in 1995. This makes it one of Taiwan's largest firms. CPT was established in 1970 to produce CRTs with technology licensed first from RCA and later from Toshiba. Toshiba maintains a small equity stake in Tatung.

Recognizing that CRTs would face increasing competition from FPDs, CPT began to study liquid crystal technology in 1988.[35] The company has struggled to keep pace with rapid FPD market changes. In 1993, CPT decided to enter manufacturing by producing STNs. In January 1994, it began producing a 9.5″ STN with technology licensed from Toshiba.

By the time this generation 1 line achieved commercial yields in mid-1995, the market standard had changed to 10.4″. CPT obtained a design for the larger format from Toshiba, only to find the market shifting again. By the time CPT designed an 11.3″ module in-house and began production in late 1996, demand had shifted to 12.1″ displays. CPT was able to design and produce the new size by mid-1997. The $100 million line currently uses either 300 mm × 370 mm or 370 mm × 470 mm substrates to produce displays ranging from 9.5″ to 15.0″. Re-tooling occurs as circumstances warrant. The plant's monthly capacity is 40,000 substrates.

Despite the company's STN difficulties, C.Y. Lee, CPT president and son of Tatung's Chairman, has established a high priority for TFT production for the notebook assembly industry and as a CRT substitute. Initially, CPT approached Toshiba's STN division, without success, to propose licensing TFT technology. In April 1997, CPT announced its TFT-LCD production alliance with ADI. Mitsubishi Electric agreed to provide startup engineering support and train CPT engineers and

35 CPT considered licensing Plasmaco's plasma display technology, which is suitable for large applications, such as wall-hanging TVs. Negotiations ended when Matsushita bought the US company in 1996.

operators in Japan. ADI expected to take up to 30 percent of the plant's output. Management hoped the generation 2.5 line would begin producing 4-up 12.1″ displays on 410 mm × 520 mm substrates in 1998 at a monthly capacity of 30,000 substrates next to the STN line. Deteriorating market conditions led to an unspecified delay in February 1998.[36]

Nan Ya Plastics. Nan Ya Plastics (1995 revenues: over $3 billion) is the latest Taiwanese entrant. Nan Ya, established in 1958, belongs to Taiwan's largest business group, the Formosa Plastics petrochemical conglomerate (1995 revenues: over $10 billion). Nan Ya produces PVCs and other plastic products as its primary business. In the 1980s the company began to diversify into electronics materials such as bare circuit boards.

Nan Ya set out to internally develop STN display technology in 1991.[37] The company had no semiconductor manufacturing experience. Consequently, management determined that Nan Ya's engineering capabilities better suited STN production than TFTs. Pilot production of 9.5″ and 10.4″ monochrome STN-LCD screens began in 1992 using all Japanese equipment. The line, located at a plant in Taipei, cost about $70 million and could run 7,500 300 mm × 350 mm substrates monthly. In 1994, the company invested about $40 million for a fully-automated plant in Taoyuan County, with a monthly capacity of 50,000 300 mm × 350 mm or 300 mm × 400 mm substrates. The company began color 10.4″ production in 1996, and added 11.3″ in 1997. Smaller sizes for non-notebook applications as well as 12.1″ displays are under development.

In 1994, at about the same time it was setting up an alliance to produce memory chips with Japan's Oki Electric, Nan Ya reportedly also tried to license TFT-LCD technology from Japan. Plans stalled in 1995 when Winston Wang, executive vice president and son of Formosa Plastics' founder, left the firm. Nan Ya plans eventually to work with a Japanese company to acquire production know-how.

THE ROLE OF GOVERNMENT POLICY IN THE TAIWANESE DISPLAY INDUSTRY

The major government agencies concerned with high technology, including ITRI and ERSO, make their home in the Ministry of Economic Affairs (MoEA). The MoEA has promoted a shift to higher-value-added production since the 1970s. As a highly automated process, local TFT production would increase value-added per worker in line with rising wages, and help replace lost jobs as firms transfer labor-intensive manufacturing to lower-wage countries. Local production would also help reduce a growing balance-of-payments deficit with Japan.[38] In 1993, this deficit topped $14 billion, TFT imports for the growing notebook PC assembly industry contributed $330 million. When the 1996 deficit fell just short of $14 billion, TFT imports accounted for almost 10 percent of it. The government forecasts that by 2000 TFT

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36 *DisplaySearch Monitor*, 2/1998.

37 First International Computer, another group member, produces notebook PCs. Company officials did not identify integration strategy, however, as strong motivation for Nan Ya's investment.

38 Taiwan's companies are leading notebook designers and hold about one third of the world assembly market. Production grew from 1 to 3.8 million from 1993 to 1996, worth $5.3 billion (*China News Agency*, May 2, 1997).

imports will top $2 billion, in the absence of domestic production.[39] In 1996, more than half of the notebooks assembled in Taiwan featured TFTs.

ERSO has played two important roles in the TFT localization drive: technology developer and private production investment promoter. Technology development began in 1986.[40] In 1988, the government enacted the multi-technology Optical Information Project, which included LCDs. The LCD program addressed product and manufacturing process design in five technology categories: microfabrication for thin-film transistors, ICs for driver chips, panel assembly, module packaging, and related materials. The first prototypes, 3″ polysilicon high-resolution displays for projection TVs, emerged in 1989. Notebook displays followed within a few years. The program also made progress in ancillary technologies such as color filters and chip-on-glass fabrication.[41]

In 1992, the Industrial Development Bureau (IDB), an MoEA agency, called for firms developing LCD technology to pool their resources.[42] Existing and potential producers attended a meeting in March 1993. There, ITRI disclosed a TFT industry strategy based on new government policy to encourage private sector leadership in technology development. ITRI would fund preliminary research at ERSO, expecting to pass it off to a private alliance.

The venture capital firm Champion Consulting responded to IDB in 1993 by forming a new alliance, Mandarin Display Manufacturing Corporation. Champion's chairman, Dr Hu Ting-Hua, also chaired Macronix, an early IC producer in Taiwan. The alliance proposed to raise $500 million to build a TFT-LCD plant. UMC, CPT, Nan Ya, Picvue and TSMC, an IC joint venture with Philips paid about $40,000 each to participate. The members split on technology choices. Japanese technology was unavailable. ERSO technology was not ready for commercialization. Philips hoped to license its modified double diode thin-film technology to the group. Members met every month or two in ERSO-staffed meetings and travelled to the Netherlands to see Philips' pilot facility (later abandoned). Unable to agree on a direction, the alliance eventually disbanded.

Two years later, ERSO brought firms together again to study its 10.4″ TFT-LCD. CPT, Nan Ya, Acer Peripherals and China Steel reportedly paid about $150,000 each to participate and dedicated engineers to the project.[43] The group continued to develop the technology, contracting with PVI for samples. But PVI declined to formally join because management believed that the costs of technology sharing would exceed the benefits of participating. ERSO planned to replicate its earlier IC strategy by supervising jointly funded pilot production before spinning off a private

39 "Taiwan to Boost LCD Production", *Chinese Economic News Service*, July 8, 1997.

40 An interesting comparison: ERSO began LCD research two years after Samsung launched its study group. In 1992 Samsung turned out a 10.4" TFT, again two years ahead of ERSO. Subsequently Samsung moved into high-volume production. ERSO's technology has languished for want of a private sector champion.

41 Both technologies were transferred to private firms: color filters to Asia Chemicals and chip-on-glass to Wintek, a producer of small monochrome STN displays ("TFT-LCD Technology", *ITRI Annual Report 1996*).

42 IDB's responsibilities included arranging preferential loans for manufacturing investments in targeted sectors.

43 "Four Taiwan Firms Forge Alliance to Make TFT-LCD", *Reuters Online*, April 18, 1995. Acer was an affiliate of Taiwan's largest PC firm. China Steel was a state-owned firm in the midst of being privatized that had just diversified into silicon wafer production for the IC industry.

joint venture. But the partners did not accept the idea and were unwilling to license the ERSO technology for high-volume production. The alliance ended.

Some participants described the meetings surrounding the alliances as useful for learning about the industry. But on the whole, the process seems to have led to a dead end. The consortia differed from successful public/private R&D alliances in other countries by focusing on technology commercialization. Japan's VLSI Project of the mid-1970s, for example, and the ongoing SEMATECH consortium in the US have focused primarily on pre-competitive research. Members receive preferential access to results, but develop, produce and market their own products (Fong 1998; Anchordoguy 1989; Stowsky 1992; Hane 1994). ERSO aimed at bringing existing technologies to the verge of high-volume production. We believe that the two ventures clashed with the traditional independence of Taiwan's business culture by asking firms to share capabilities they considered proprietary.

A TALE OF TWO CASES

The cases differ sharply. Korean firms outpaced the Taiwanese in both the timing and size of TFT-LCD investments (see Table 3). The *chaebols* closed the technology gap with Japan in output markets, but relied on their erstwhile rivals for key capital equipment they used to take the lead. If the Koreans make progress in FPD equipment and materials industries, their experience calls Asia sceptics' views into question. The Taiwan picture appears more murky.

We begin this section by asking how historic differences in national industrial strategies contributed to differences between Korean and Taiwanese firms' choices in the FPD industry. We argue that industrial strategies in older industries have influenced industry structure and the nature of strategic interaction in the two countries. But in this new industry, the structural consequences of past strategies have limited government discretion and broadened the scope for firms' strategic choices. We will discuss how national institutions, firm growth and the accelerating pace of change in high technology constrained governments' abilities to intervene in TFTs.[44]

Korea and Taiwan: contrasting studies in development

The Korean and Taiwanese firms in our study differ greatly in size. The two principle producers, Samsung and LG respectively earned 1995 revenues of $14 billion and $6 billion. Only one Taiwanese entrant, Nan Ya, enjoys comparable cash flow. The Korean firms compare favorably in size with their Japanese rivals.[45] Comparable size differences between Korean and Taiwanese firms pertain throughout both economies. In 1983, the top five Korean firms' sales equalled 52 percent of GNP, while the

44 Hong (1992) makes a similar argument for Taiwan and Korea in semiconductors; Borrus (1988: Ch. 3), for Japanese and US chip sectors; Murtha *et al.* (1996) for FPDs in Japan and the US. Murtha and Lenway (1994) offer a general framework relating industrial strategies to multinational corporate strategy.

45 Sharp leads the FPD industry in global revenue and has corporate revenues of around $10 billion. Such domestic rivals as Matsushita and NEC have sales two or three times larger. The smallest Japanese notebook display producer, Hosiden, is comparable in size to the Taiwanese firms (total revenues: about $750 million, fiscal year ending March 1994).

TABLE 3: TFT-LCD FACTORIES IN KOREA AND TAIWAN

	1992	1993	1994	1995	1996	1997	Planned
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 20,000 13.3″
LG	pilot (1990)			Gen. 2 10,000 10.4″		Gen. 3.5 20,000 12.1″	
Hyundai	US pilot			Gen. 2 12,000 10.4″	Gen. 3 5,000 12.1″		Gen. 3.5 10,000 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″
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, initial capacity in substrates per month, and primary display size produced (TFT-LCD except where indicated). Dates given are the first year of operation. Post-1996 figures are authors' estimates. Sources: Business press and interview materials.

top 50 accounted for 90 percent. Sales of the top five Taiwanese groups accounted for 10 percent of GNP, and the top 100, 32 percent (Fields 1995: 6). These differences in industry structure emerged in part from differences in industrial strategies. Each government launched an export drive in the 1960s (World Bank 1993: 127–134). Credit rationing played a central role in both cases.[46] The Korean government directed credit to a few favored groups' firms which grew larger and larger.[47] The Taiwanese government spread the funds to avoid fostering comparable national champions.

Despite efforts at financial deregulation, the Korean government continued to provide cheap credit access in the 1990s,[48] creating an important competitive weapon for the *chaebols* as well as a tendency toward excess capacity in their industries. Korean managers assured us that their companies enjoyed easy access to capital for TFT expansion. Top managers spoke of an imperative to invest with a view to future markets, even if cyclical products like DRAMs and TFT-LCDs generated inconsistent profit streams. We believe this partially explains Korean FPD firms' capabilities to specialize in more advanced, capital-intensive, higher-value-added goods than did the Taiwanese firms. The latter concentrated on STNs and small TFTs, which had a lower value per square inch than notebook displays.[49]

Taiwanese managers argued that their firms' smaller sizes, lower cash flow and greater reliance on equity markets raised the relevance to strategy of short-term performance criteria. Is it possible that deeper institutional explanation underlie their perspective? Hamilton and Biggard (1988) have suggested that Chinese norms of equal inheritance among sons may multiply individual property holdings. Wade (1990) suggested that the ruling party, which originated on the mainland, may have erected obstacles to large enterprise out of concern that native-Taiwanese-owned firms might contribute to the political opposition. Taiwanese firms typically spin off new activities into new corporations that maintain financial linkages but operate independently. In times of economic boom, valued employees sometimes convert their bonuses into capitalization for new firms, observing the proverb, "it is better to be the head of a chicken than the tail of an ox".

The governments have adapted their roles to these institutional differences. Both have continued to use tax incentives and administrative guidance to promote high-technology industries. But neither government has successfully directly intervened in TFT-LCDs. The limited role of direct intervention has different explanations in the two cases. In Korea, firms did not require direct government assistance. In Taiwan, the government failed to spin off its TFT technology to a private company and to create a production consortium because it could not resolve collective action problems among the many small private firms involved.

46 See Patrick (1994), especially p. 333.

47 Park (1994: 162–163); the Korean government set a goal to replicate Japan's industrial structure.

48 Park (1994: 155). Financial liberalization has advanced slowly in both countries. Large size and high industry concentration, however, have particularly enhanced Korean firms' political power and capabilities to forestall change. We expect the 1997 currency crisis and consequent IMF agreement to speed Korean reform.

49 This contrast also held for ICs. When Samsung began producing memory chips in the early 1980s, the sole Taiwanese IC producer made application-specific chips that could be produced profitably on a smaller scale using simpler process technology. Taiwanese firms only recently opened large-scale plants for memory chips.

Technology choices in Korea and Taiwan

Korean firms have entered established high-technology industries that require investments of massive scale. Taiwanese firms have succeeded through niche strategies, building outward from opportunities with relatively low initial resource commitments.[50] Many Taiwanese firms seem to exemplify flexible specialization,[51] and a business style that Lam and Lee called "guerrilla capitalism". Small, flexible, and responsive to market shifts, guerrilla capitalist companies exploit short-term profit opportunities and demonstrate a "lack of commitment to any particular product or industry" (1992: 208). This description seems inappropriate to well-established firms like CPT or Nan Ya. But it seems to fit Unipac, which opportunistically shifted from fax components parts to TFTs and became the first commercial producer in Taiwan. Unipac has since diversified into microdisplays and FEDs, rather than pursue notebook computer displays as Korean firms did.

Korean firms made their choices in a context of vertical integration encompassing intermediate inputs such as color filters and downstream products such as laptops and desktop monitors. The companies in Taiwan's fragmented high tech sector rarely engaged in vertical integration. This has several consequences in advanced displays. The lack of upstream integration means that firms must purchase key inputs on the market. This may enhance flexibility in times of rapid technological change, but it creates a liability when shortages develop in input markets. The computer assemblers' small average size deprives them of the security of supply that buying power could afford them in global markets. As long as any assembler or group of assemblers declines to integrate backward into advanced display manufacture, Taiwan's computer firms risk missing out on the most profitable consumer market segments, including the coming boom in TFT-LCD desktop monitors. Korean firms entered the TFT industry to secure a vision for their groups' futures in downstream product markets such as multimedia. Taiwanese firms have entered the business to leverage manufacturing competencies, or defensively, as in the case of CPT, which faces losing its CRT market.

Differences in integration also affect access to skilled labor. *Chaebols* encompass a range of activities and can re-assign engineers with the requisite skills based on group priorities. Taiwanese firms that shift focus compete against each other for engineers on the open market. Korean firms have courted head-to-head competition with market leaders, particularly the Japanese. They often begin by licensing, but then undertake internal development to place future partnerships on an equal footing (e.g. Samsung and Fujitsu; LG and Alps). Taiwanese firms typically pursue strategies of vertical supply rather than competition, as exemplified by the recent alliance between CPT and ADI, and Unipac's FED and microdisplay foundry strategy.

DISCUSSION AND CONCLUSION

The lead goose appears vulnerable. Many Japanese companies committed resources to FPDs hoping for direct, long-term profits. With or without direct profits, Japanese

50 This point is similar to the analysis in Levy and Kuo (1991). See also Mody (1990).

51 The term originated with Piore and Sabel (1984).

firms recognized that advanced displays can determine competitive options both for price leadership and differentiation strategies in downstream markets, such as multimedia. The surprising Korean entry drove prices down and increased availability. This was a setback on all of these counts.

Samsung's success in 1995 presaged the end of Japan's near monopoly status as the global center of gravity for TFT-LCD manufacturing. Secondary Japanese producers have joined Samsung and LG in shared development projects. Korean firms have taken the lead in some areas. LG has worked with Photon Dynamics in the US to develop array test equipment for zero-defect production. Korean firms anticipated the desktop market by committing substantial capacity to technically challenging larger substrates suited to desktop monitors. Samsung opened the world's first 600 mm × 720 mm substrate production line in February 1998. If key industry observers' predictions hold true (DisplaySearch 1998), LG will hold TFT capacity second only to DTI, the joint venture between IBM and Toshiba producing in Japan (Table 1). At least in this industry, the technological gap has closed.

Our evidence suggests that countries' capabilities to close technological gaps depends on at least three factors: firms' capabilities, firms' access to capital, and firms' access to technology. Korean firms carry a wide range of engineering capabilities within their business groups. Taiwanese firms must depend to a greater degree on labor markets when they expand or diversify. Preferential treatment by the Korean banking system offers the largest Korean firms ready access to debt, and we believe that financial surpluses from the DRAM market have contributed to their abilities to acquire technology and to invest in it at efficient scale. The *chaebols* entered the TFT industry before it became feasible to license all necessary know-how from Japan. They bridged the gap with strategies that combined alliances with US firms, crash R&D programs, and capital equipment purchases that included substantial supplier support. The Korean firms have taken steps to avoid depending on Japanese FPD equipment. In stand-alone programs and collectively through EDIRAK, they have developed tools for dry etch, cell gap control, film thickness measurement and other processes.[52]

Taiwanese firms have avoided advanced-generation equipment. Managers consistently stated that they preferred stabilized generations, quick implementation and little uncertainty. In mature industry segments, process management outweighs engineering as a strategy driver, drawing on the strengths of these companies. Nonetheless, Taiwanese companies have lost ground to the market leaders, who gained significant benefits from learning by doing.[53]

We believe that the persistence or disappearance of technological gaps in FPDs has depended more on industry structure in follower countries than on the abilities of technology leaders to control the diffusion of know-how. Rapid changes in technol-

52 "EDIRAK Builds Bridges in Support of FPD Industry in Korea", *Channel Magazine*, 10(3): April 1997.

53 Technological gaps can multiply across sectors when learning by doing is important. Taiwanese firms entered memory chip production late. Mastery in this technology facilitated Korea's TFT production entry. Taiwan's memory producers presently focus all available resources on expanding to meet the next market upturn rather than diversifying into displays. Lack of chip and TFT experience saddles the Taiwanese with a double learning deficit.

ogy, particularly substrate sizes, have delivered the prize of market leadership to companies that concentrated their resources on continuous innovation rather than on defending the *status quo*. Japan's companies do not have a monopoly on continuous innovation. Cheap credit helped the Korean display industry to catch up with the leaders based in Japan. But the aggressive *chaebol* engineering groups probably helped more. Taiwan's fragmented industry structure appears as a chief impediment to a similar feat. In this sense, the technological gap framework, which focuses on country capabilities, seems more fitting than the flying geese metaphor. We believe, however, that the pessimistic conclusions of both schools probably rely too heavily on historical data on heavy industries.

Both cases illustrate how a country's past strategies affect firms' internal resources and the external opportunities that define managers' strategic choices. This perspective highlights the challenges that high technology firms face to leverage competencies, not just products, to occupy and sustain positions at key nodes in production networks. The Korean push into advanced displays, coupled with downstream developments of new notebook models, LCD monitors, and expanded advertising campaigns, may have built competencies for global network leadership around capabilities in a key component. The precedent exists for leveraging upstream TFT capabilities into notebook market dominance. In October 1997, IBM and Toshiba, alliance partners in DTI, held the number one and two positions in notebook market shares at 18.7 and 12.4 percent. These had remained stable for more than a year.[54] We attribute these successes in part to the alliance which, through its first mover status in generation 3 technologies, allowed the leaders to gain a differentiation advantage by increasing laptop screen sizes.

The niche strategies and small size of Taiwanese firms lend themselves more readily to rent dissipation than accumulation. Taiwan's assemblers have made themselves indispensable partners for PC firms in the US, Europe, and Japan. Japanese computer firms turned *en masse* to the Taiwanese to speed entry into the personal computer market. But with the exception of Acer, small size and lack of integration have prevented Taiwanese notebook and PC assemblers from developing significant leverage within their networks. Their competitive advantages derive from cost, speed, and quality management. But lack of buying power and competition among themselves have prevented them from capitalizing on these skills. These advantages have not proved sustainable.

Why did Korean and Taiwanese companies enter the FPD display industry using such divergent strategies? The differences may have a basis in industry structures that emerged from historic industrial strategies. But they have nothing to do with government targeting in contemporary times. In both countries, firm capabilities, corporate strategies and a blistering pace of change overwhelmed government initiatives. Taiwanese companies' conservative strategies grew out of limited access to capital and engineering expertise rather than the inability to acquire technology from Japan. Early Japanese successes did not prevent innovative Korean companies from building the capabilities to push ahead into next generation products. Our research

54 *Computer Resellers News*, October 6, 1997.

suggests that this industry, like all high technology industries, is a moving target (Murtha *et al.* 1996), not a sitting duck.

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