Trade and Investment Strategies in the
Flat Panel Display Industry (1968-1998)

The term Flat Panel Display (FPD) refers to a class of high performance electronic displays that have a variety of applications in the visually oriented technologies of the information age. While the initial materials and electronics advances in this industry were developed in laboratories in the United States, Japanese firms established an early lead in commercial manufacturing processes and achieved a dominant global market share, allowing them to dictate future trends in the industry.

The failure of U.S. firms to establish a significant market share and manufacturing base for FPD's formed the background to a high profile debate in business, government, and academia about the future of U.S. manufacturing in high technology areas, the problems facing U.S. firms in competition with Japanese industry, and the links between technology and trade policies and national security.

Flat Panel Display Case: Working Summary

Introduction & Early Japanese Industry Development

The term *Flat Panel Displays* refers to a class of advanced display technologies, also referred to as high information content displays, that have various advantages over traditional Cathode Ray Tube technology. In general they are light in weight, occupy a comparatively small volumn and require modest amounts of power. The most advanced display's in operation today, as we see in lap top computers, hand held cameras, and High Definition TV prototypes, are capable of delivering high definition, full color video images. Thus we can see there has been a great deal of development since the first FPD's were applied in hand held calculators and digital watches.

Another characteristic of the Flat Panel Display industry is that there are several technologies competing dominant market share and for a variety of niche applications. These types of displays and there strengths include:

Active/Passive Matrix LCD's - Thanks to massive investment outlays on the part of Japanese companies during the 1980's Liquid Crystal Displays are set to become the dominant commercial display technology. There are four main types which can be grouped into active and passive LCD's, which differ in the way they address the pixels on the screen (the pixels are composed of liquid crystals which have the ability to polarize light in the presence of an electric field). The main advantage of LCD screens is there versatility, their lower power consumption and small size, high contrast ratio's and fast writing speed, and full-color capability. Their main drawbacks are narrow viewing angles and limited contrast (which you see on your lap top computers), and the difficulties associated with manufacturing them, including very low yield rates and high initial capital investments.

Plasma Display Panels - These displays operate by controlling the light discharges from ionized gases. Their advantage is that they are currently the largest FPD's currently available. In addition they are based upon proven and reliable technologies (hence higher yield rates and lower initial cost), are very rugged and have a long lifetime. Disadvantage is they require high voltages to operate. There are not many consumer oriented applications, mostly they are military and industrial oriented. However they could be asuccessful candidate for HDTV.

Field Emission Displays - This is a prototypical display technology that is basically an improved and flatter CRT using semiconductor technology. May be a strong candidtae for HDTV but is an untested technology.

Electroluminescent Displays - Like Plasma Display Panels and the famous LED's, ELD's are emissive displays (they generate their own light from a phosphor sandwiched between electrodes.) They are similar to LCD's in that they can be addressed actively or passively. Their advantages are that they are very thin and compact, have high writing speed and good brightness levels, and operate at low voltages. Current application are mostly military, ATM machines, and industrial display's.

American Invention and Japanese Development

There are several factors which have driven development of the FPD industry. On the technical level the development of commercially viable displays was an incremental process driven by advances in materials technologies and micro-electronics systems to address the screens. The main production breakthroughs have been increasing yield rates and developing the ability to produce larger screens and full color technologies.

Although most of the technical breakthroughs and discoveries in FPD's were made in U.S. labs, for a variety of reasons that I believe will be mentioned later U.S. firms either did not pursue commercial product development, pursued overly narrow technologies for niche military production, or followed technical dead ends.

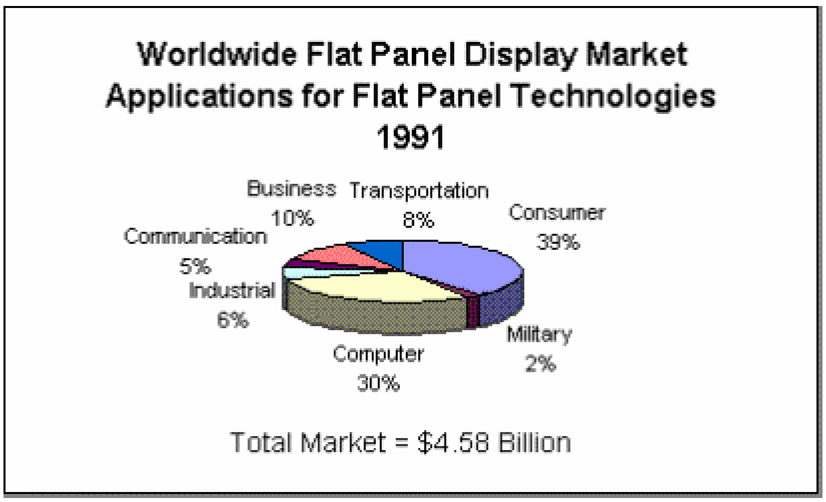
In Japan private industry, led by Sharp Corporation, took succeeding developments in FPD technologies and quickly translated them into commercial technologies. While many observers have pointed to the Japanese government role in developing the FPD industry, in reality MITI's role was questionable. Even today Flat Panels themselves are not considered to be a profit making enterprise, nonetheless the motivating factors driving Japanese private investment were seen as including:

-the severely competitive Japanese electronics industry put a premium on a rapid turnover in new commercial technologies. For instance Sharp introduced LCD's into calculators first to beat off severe competition from Casio. Once these displays were integrated into commercial products the race was on to build larger displays with wider application to consumer electronics. It has also been pointed out that in the context of this competition Japanese firms have generally been willing and able to absorb short term losses in order to establish first mover advantages in new products.

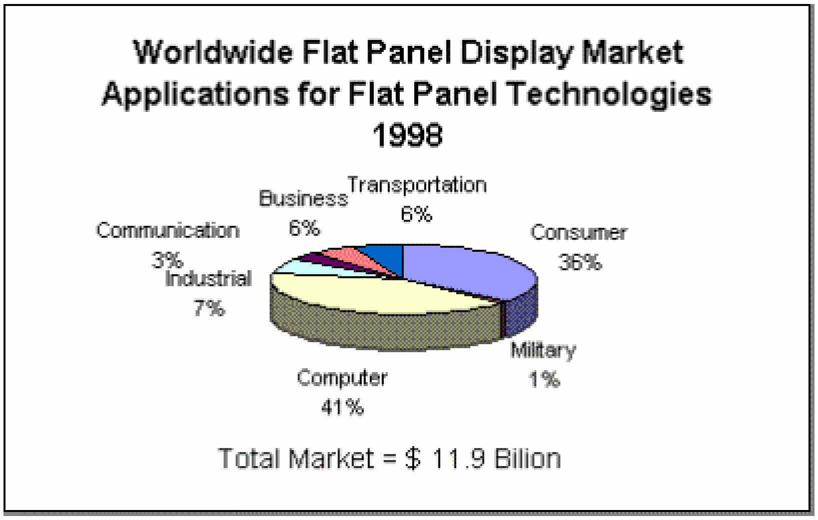
-another obvious factor was the ability of Japanese firms to license key technologies from U.S. and British sources. The bulk of the new discoveries in materials and technologies have been in U.S. university and corporate labs, though the Europeans have contributed a lot to materials research. The key here has been translating basic research into production techniques. This said, it must be noted that Japanese basic research is at new levels, with advances not just in production processes but also materials coming out of Japanese University and corporate labs.

- Investments have been the overriding factor. Through massive outlays Japanese firms have been able to determine the direction of the industry and have established first mover advantages, external and internal economies of scale, and have defined the architecture of supply in a technology with a wide variety of commercial, political, and security implications.

Consumer	36%
Military	2%
Computer	30%
Industrial	6%
Communication	5%
Business	10%
Transportation	8%



Consumer	36%
Military	1%
Computer	41%
Industrial	7%
Communication	3%
Business	6%
Transportation	6%



Technology and Investment Strategies in the Flat Panel Display Industry

Case A (1968-1988)

Introduction

In 1988 the U.S. Department of Defense (DoD) issued a Broad Area Announcement (BAA) to award competitive grants for the research and development of domestic Flat Panel Display (FPD) display manufacturing capabilities. The DoD projected an increasing demand for advanced display technologies for use in battlefield and logistical information systems, but was concerned that the United States lacked a competitive domestic industry from which procure these strategic components. Although the various FPD technologies and applications had been developed primarily by U.S. electronics and computer firms, only the large consumer electronics firms in Japan had entered into high volume production of FPD's.

At the same time several large American electronics and computer companies were realizing that they had similar concerns. From humble origins as compact, energy efficient devices for simple digital displays on calculators and wrist watches, FPD's had evolved into high-cost, strategic inputs for an array of high value added products, including lap-top computers, portable televisions, medical and aerospace instruments, and High Definition Television (HDTV). However, high volume production in this industry would require enormous investments and would not guarantee manufacturing success. Furthermore, the structure of the industry, both in terms of supply and demand pricing considerations, and in terms of specific technology applications, had evolved primarily out of competition in Japan between large integrated consumer electronics firms. *Why is this important?*

The difficult investment decisions facing potential American entrants to the FPD industry highlighted an array of factors specific to high technology industries that determined manufacturing success. These included science and industrial policies at the national level, firm strategies and organizational structure, access to technology and investment, and market structure. How these factors influenced success in the FPD industry is the subject of the following study.

I. The Knowledge Economy

Following World War II the United States stood at the threshold of a new economic era. The once agrarian nation had just defeated two of the greatest armed powers in history, largely by having developed an overwhelming superiority in basic scientific research, technology development, and industrial production during the war. The first true computers were wartime inventions deriving from efforts to track targets for artillery fire. Likewise, the science of operations management arose out of American efforts to handle the logistical difficulties incurred in mobilizing the resources needed to prosecute a global war.

These and other successes reflected a basic reality of modern warfare: victory on the battlefield had become dependent upon knowledge and technical innovation at home, in the form of new weapons technologies, advanced logistics, and new methods of harnessing human resources. It was also clear however, that the spin-offs from basic knowledge could be equally applied in the private sector during peacetime.

As early as 1945 Vannevar Bush, who had organized the mobilization of America's scientific resources during the war, had this to say on the view that the future economic success of American industry would come to depend largely upon basic science:

"Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. New products and processes do not appear full-grown. They are founded on new principles and new conceptions which in turn are painstakingly developed by research in the purest realms of science."

This view of the application of basic knowledge to commercial innovations would form a unique compliment to American economic beliefs, which traditionally counsel against government intervention the form of industrial policies. The dream of Vannevar Bush and other planners within government and the private sector was to "spin-off" new technologies developed primarily for military applications into high-tech products for commercial markets. The spin-off concept essentially viewed the migration of military technologies to the private sector as a positive externality derived from government science policies; not a rationale for such, but certainly an added benefit.

At the same time, many leading American firms established their own basic research programs. AT&T's Bell Laboratories in New Jersey and Xerox's Palo Alto Research Center (PARC) were only the most famous examples of private industry initiatives that achieved the type of advances in basic research and development usually found only in government laboratories or large universities. Underlying the large investments these companies made in their research programs was a tacit faith that once demand was sufficient, their own entrepreneurial and productive expertise would be sufficient for them to bring new products to market and thus recoup their investments.

For the most part they were correct in their assumptions. By the end of the 1960's U.S. firms had established seemingly insurmountable leads over their overseas competitors in almost every high-technology sector. A succession of U.S. inventions, from the transistor, to the integrated circuit, to semiconductor technology, suggested an incipient revolution in communications technologies and explosive future growth in a host of consumer markets based on applications of microelectronics to entertainment and educational products. What was remarkable about the new products made possible by these technologies was their new capacity to store and manipulate information. Left to the realm of science fiction however was the myriad of possibilities for how that information would eventually be displayed.

II. FPD Research and Development in the United States

One industry in which U.S. firms were clearly dominant was in the production of televisions. The leading firms in this market were household names whose longevity had enshrined them in American lore: General Electric, RCA, Westinghouse, and Zenith. The color televisions produced within the consumer electronics divisions of these companies were the best in the world, but the Cathode Ray Tube (CRT) technology they used provided consumers with televisions that were bulky, consumed massive amounts of power, and often produced grainy images. For years visionaries had dreamed of developing new display technologies that could be used to produce next generation televisions, with flat screens thin enough to hang on a wall and with improved display capabilities.

Accordingly, beginning in the late 1960's and early 1970's these firms made substantial investments in research programs to develop Flat Panel Display (FPD) technologies. Various display innovations during this period developed visions for the potential uses of FPD's and set the templates for future technology trends. However, for various reasons none of the leading American consumer electronics firms managed to apply the most advanced display technologies that were researched, such as Active Matrix Liquid Crystal Display's (AM-LCD'S) and Electro Luminescent Display's (ELD'S), to new commercial products.

The first applications of Liquid Crystals to display technology were at RCA's Sarnoff Laboratory, where as early as 1968 the technology was viewed as a future alternative not only for television screens but also to produce clocks and watches with simple alpha-numeric electronic displays. Although RCA became the most noted domestic champion of what were termed *high information content displays* for the consumer market, internal corporate decisions prevented the new LCD technologies from getting out of the lab. LCD's were viewed as a threat to the CRT industry in which RCA had a large sunken investment. At the same time, RCA's management was questioning the company's committment to the commercial electronics market. Eventually the company was purchased by General Electric and later sold to the French firm Thomsom. Accordingly, work on LCD's at Sarnoff Laboratories was suspended from 1970-1983 in favor of more conventional research on advanced CRT displays.

Westinghouse pursued research on LCD technologies in the same time period. It was here that the Active Matrix approach to addressing LCD's was invented. But despite investing several million dollars in R&D and successfully demonstrating prototype LCD and Electro Luminescent Displays (ELD's) Westinghouse decided not to enter into the FPD business. Primarily this decision stemmed from Westinghouse's increasingly weak position within the consumer television industry, which counseled against sinking additional capital into a risky R&D effort for new screen technologies. With no remaining economic rationale for researching this prototype technology, Westinghouse canceled its LCD program in 1979.

General Electric also carried out research on LCD's in the 1970's, in a program that was merged with RCA's for a short time after GE purchased the company in. However, G.E.'s corporate strategy came to focus on systems assembly, rather than a components approach to producing consumer electronics, meaning that screen technologies were viewed simply as components to be purchased at the lowest possible cost.. While the company did produce a limited number of displays for military applications, despite purchasing RCA GE subsequently divested from its entire consumer electronics group and sold RCA to the French firm Thomson Electronics. This reflected a general trend in the U.S. electronics industry, whereby large integrated manufacturing firms either let go of large segments of their consumer electronics divisions, or gradually focused more final product assembly rather than integrated components manufacturing.

III. The Japanese Commercialization of FPD Technologies

While American firms continued to research visionary applications for the new display technologies, they began licensing basic LCD and Light Emitting Diode (LED) technologies to Japanese consumer electronics firms. Japanese companies quickly incorporated the new technologies in the lower end, high volume markets for devices requiring the most rudimentary displays, such as calculators and digital watches. At the time this was generally not even viewed as an economic issue. U.S. firms were more than happy to license these technologies because they had very little interest in focusing their investment efforts on the type of high-volume, low cost electronic gadgets that Japanese companies were producing at the time. Moreover, barriers to trade and investment within the Japanese market made licensing agreements the only feasable approach to earning a return on investments there.

However, Japanese firms viewed initial applications for FPD's in a much different manner than their American counterparts. At the time they knew they could never hope to compete with America's advanced R&D and manufacturing prowess, but early on they adopted long-term outlooks towards the new display technologies, possibly hoping to translate accumulated experience into a strategy to catch up. In part this was encouraged by government industrial policies.

While the early Japanese entrants to the FPD market did not benefit from specific industrial policy programs targeting the industry, they did benefit from an array of technology policies and macroeconomic conditions which provided a favorable investment climate and contributed to overall firm technology strategies. Foremost were the efforts of Japan's Ministry of International Trade and Industry (MITI) to promote the importation of foreign technologies for use in domestic manufacturing. MITI's curbs on foreign direct investment limited U.S. and European firms to licensing patents to their Japanese counterparts. In addition to keeping tabs on promising overseas manufacturing developments, MITI would often assist firms in their negotiations for licensing rights and would monitor and help guide their implementation into informal guidelines suggesting what directions the industry should take.

The macroeconomic climate informing firm investment behaviors in Japan was focused on the provision of low cost capital loans, tax incentives and subsidies for research and development, accelerated depreciation allowances, and tax deductions for exports. These and other measures encouraged Japanese firms to make large capital and R&D investments, and allowed them to develop long term strategies for market development. This allowed for long production runs characterized by enormous manufacturing volumes, in turn allowing Japanese firms to realize substantial internal economies of scale. This translated directly into increased productivity and decreased production costs. Most important for microelectronics and FPD's in particular, it meant accumulated manufacturing experience that allowed them to realize increased yield rates.

These policies and economic conditions allowed Japanese firms to establish a strong manufacturing presence in the new display technologies. Subsequent developments in the incipient FPD industry have been explained by examining how characteristics of the domestic market structures conditioned how American and Japanese firms prospered in global consumer electronics markets. In both countries success in microelectronics has rested very heavily upon innovations in manufacturing processes. The subject of how firms and nations are able to sustain what are referred to as "national systems of innovation" is much debated. Ultimately, the key to innovation is the application of knowledge to productive purposes: as we have seen the American post-war vision was that a lead in pure scientific knowledge could be translated into a sustained lead in manufacturing. The link in this chain was the free market mechanism, in which the dictates of supply and demand would guide firm behavior in allocating the proper investments in R&D that would lead to new innovations.

The strategies of Japanese firms demonstrated a different approach towards knowledge and innovation. In contrast to the American emphasis of basic research as the fountain of innovation, in Japan discoveries and inventions were generally viewed as lesser in importance to direct applications. In acting this way Japanese firms, perhaps unknowingly, echoed the advice of the Austrian economist Schumpeter, who argued that inventions in and of themselves had no economic impact: it was only when an invention or discovery was applied in a new productive arrangement that an innovation could take place. Japanese firms typically followed this informal logic by importing and then incrementally improving on Western technologies by focusing on innovations in the manufacturing process.

Typical of these efforts was the Sharp Corporation. Like GE, Sharp had primarily been an assembler of finished products or integrated systems. However, by the 1970's Sharp was pursuing corporate technology strategies directly the opposite of G.E.'s. Sharp invested in FPD technologies as part of this long-term corporate strategy of maintaining a competitive edge in components as well as finished products. By the time Sharp entered the display market its competitive strategies had been honed in Japan's intensely competitive semiconductor and electronic desktop calculator industries. Because MITI had used industrial policies to foster industry wide upgrades in technology and investment capabilities, success in the domestic consumer electronics sector was dependent upon extremely rapid innovations in process technologies and in being the first to bring new products or innovations to market.

In the FPD field Sharp's strategy was to apply the most basic LED and LCD technologies to high volume commercial products, such as calculators and wristwatches, in order to outpace domestic rivals. For instance, in the market for electronic calculators Sharp introduced LCD's along with integrated circuits and photovoltaic cells into new designs which gave them competitive advantages over Casio, and allowed them to dominate both the Japanese and export markets. Clearly these advantages were dependent upon identifying both new manufacturing possibilities and new marketing arrangements, i.e. the application of display technologies to new products.

IV. Maturation of the FPD Industry

By the early 1980's two trends were converging to give a more definite shape to the FPD industry. Advances in the miniaturization of electronics components and in the computer industry were making it realistic to consider manufacturing new products such as hand held televisions, laptop computers, *and an array of other consumer and industrial devices*. All of these would require compact, high definition screens with low power draw. Secondly, futurists and long-term planners saw the new communications technologies as ushering in an information revolution in which a plethora of human activities would be mediated by machine interfaces, increasingly in the form of sophisticated visual displays. These trends suggested the potential for exponential growth in the display market, but significant technical barriers and investment decisions remained.

Because of the large Japanese investments in the technology, the greater share of research and manufacturing efforts was increasingly devoted to LCD's. However, they were extraordinarily expensive and difficult to manufacture. Furthermore this display technology had several shortcomings. They were not very bright displays, resulting in "fuzzy" resolution and difficulties viewing them at angles and in sunlight. Most importantly they were difficult to scale upwards in size to meet the demand for larger displays. Nevertheless there were crucial advantages to using LCD's, not least of which were their low power consumption and the high speeds at which they could display information.

While several Japanese companies had explored other FPD technologies, including ELD and Plasma displays, the leading manufacturers including Sharp, Toshiba, Hitachi, NEC, and Hosiden gradually focused their efforts entirely on successive generations of LCD's. This strategy was appealing for two reasons. First, these manufacturers could parlay their experiences in low end, high volume manufacturing into lower production costs and higher yields as they attempted to manufacture higher end displays. Secondly, the successive advances in LCD technology were increasing the potential size of the displays, improving display quality, and making it possible to produce high quality color displays.

The promise of these new developments finally lured the Japanese government into initiating cooperative programs, beginning in 1988. The Ministry of International Trade and Industry (MITI) and the Ministry of Posts and Telecommunications (MPT) jointly established Japan's Key Technology Center (JTEC) as a publicly funded research consortium to work with private firms to identify technological goals for the industry. More directly, the government established the Giant Technology Corporation (GTC) and the High Definition Television Engineering Corporation (HDTEC). These efforts were funded jointly by private firms and by JTEC, to the tune of $25 million and $30 million respectively. However, these investments were dwarfed by the $3 billion Japanese firms had already spent developing LCD's for smaller scale applications.

While the latter two programs focused specifically on displays for HDTV and LCD video projection systems, they were most significant in that they announced the Japanese intention scale LCD technologies towards larger and more advanced applications. The ambitious nature of these projects signaled key changes in the FPD industry. At the same time that the increased size and quality of the displays was creating new opportunities to market new products, the increasing cost and R&D intensity of producing LCD'S would confront U.S. electronics and computer firms with difficult decisions.

V. FPD Manufacturing in the United States

Promising FPD technologies continued to be advanced in U.S. research efforts through the 1980's. While the old guard consumer electronics firms had exited the industry, several more specialized electronics firms such as Xerox, Motorola, Texas Instruments, and Raytheon, as well American computer firms such as IBM, Compaq, and Apple, were realizing the increasing importance of displays as strategic inputs to their final products. Raytheon had more than 40 years of experience in manufacturing CRT displays for military, avionics, and other high end commercial applications. Texas Instruments had dabbled in FPD's since the seventies, evaluating the suitability of using plasma display panels (PDP's), electroluminescent displays (ELD's), or LCD's to supply in house demand for watch and calculator screens. However, management at the company decided that in house demand was insufficient to enter into FPD manufacturing, and the company did not at the time want to become an outside vendor. In addition to investment barriers, another factor counseling caution to would be investors in the FPD market was the volatility of supply and demand in the industry, added to uncertainty over which FPD technologies would prevail in future applications.

None of the others had any substantial experience in manufacturing displays for commercial markets. This would become a more pressing problem for the computer companies as laptop computers and "green" PC's added to their demand for the new display technologies. This led the main innovators in the PC market, primarily Apple, Compaq, and IBM to strategize on how best to guarantee adequate supply of the new displays. A brief list of options facing these companies would include investing in their own high volume manufacturing capability, entering into joint production arrangements with other firms, or simply sourcing the screens from Japanese suppliers who were also their main competitors.

Questions for discussion

Assess the differing American and Japanese approaches towards utilizing knowledge in the pursuit of innovations. What are the advantages and disadvantages of each?

From a marketing and investment standpoint, assess the decisions of the large US consumer electronics firms not to enter into advanced display manufacturing ?

Was there an identifiable market failure? What could have been done to correct it?

American and Japanese firms saw the potential applications for FPD's in very different terms. US firms developed visionary uses for high definition televisions and other more limited applications, based upon their tremendous lead in technology and manufacturing, while the Japanese focused on lower end, high volume applications with immediate commercial potential. Which strategy would you expect to yield long term success in the industry?

Discuss Japanese industrial policies with reference to the Ricardian theory of comparative advantage and the Heckscher-Ohlin factor endowments model of international trade. Does the Japanese model make since in these terms? If so, how? If not, in what ways might it succeed? Is this a new model?

At this point, should the potential consumers of FPD's have entered into high volume display production would it make more since for them to buy these components from existing Japanese manufacturers. What are the implications of each decision? What obstacles would confront the firms in each decision? Who else might care?

Case A Exhibits

Exhibit 1.

Phases of Industrial Development

Phase	Technology is	Innovation is in	Innovation comes from
1	fluid	products	diverse sources
2	specific	processes	competition in production processes
3	re-fluidized	systems	integration

Source: Kenichi Imai, *Japan's Industrial Policy for High Technology Industry,* 1986.