

5 Technonationalism and cooperation in a globalizing industry

The case of flat-panel displays¹

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Introduction

Can government technology programs promote the successful commercialization of innovations without leveraging experience and learning accessible only outside the United States? We investigate this question in the context of US government efforts to jump-start a domestic flat-panel display industry from 1988 to 1998. Flat-panel displays (FPDs) are thin screens used predominantly in laptop and notebook computers. As FPD prices decline, they have migrated to the desktop and begun to replace CRTs as monitors for computers.

FPDs are produced predominantly in Asia with current production divided between Japan (about 80 percent of displays used in notebook computers) and Korea, which has the remaining 20 percent of the market. While the annual value of production of all types of FPDs was about \$14 billion in 1998 (Stanford Resources, 1998), by 2002 analysts expect that the FPD market will exceed \$30 billion. A significant proportion of the increase in production capacity to meet the new demand may come from Taiwanese firms, which are planning to make major investments in anticipation of a shortfall in supply resulting from the Asian financial crisis.

Because of the centrality of the technology to many high-tech and high-value-added products and many kinds of electronic systems essential to military preparedness, policymakers in several countries have expressed concern about the strategic importance of the FPD industry to their national economies. The conventional view is that firms in Europe and the United States have been unable or unwilling, for the most part, to make the large and risky investments needed to compete in this particular market. Governments and firms in those two regions are concerned that they may be ceding too much technological leadership to Asia by not participating more directly in the design and manufacturing of advanced displays.² In Korea, policymakers fear the possible economic weakness that could result

from domestic firms' dependence on Japanese manufacturing tools and materials. In Taiwan, government officials worry that laptop and notebook assemblers depend too much on Japan and Korea for advanced displays. Although the Japanese government has not played a large role in the development of the industry, government officials express concern about industry volatility and the disruptive effects of the lack of standards and the appearance of sudden overcapacity accompanied by rapid price declines.

As a result, governments, industry associations and individual firms have devised various strategies to enhance their ability to compete in global markets while reducing their perceived dependencies on other countries. In order for policymakers to garner the necessary broad-based political support, these interventions often have been motivated by what we call "technonationalism." *Technonationalism* is a desire to replicate many aspects of the technology commercialization process using domestic capabilities as part of a broader strategy to keep up with the international competition in high technologies. Ironically, in a highly globalized industry in which cutting-edge understanding and experience with the technology is dispersed globally, like the one which currently characterizes flat-panel displays, technonationalism is counterproductive. While technonationalist policies constrain domestic firms to work with their domestic counterparts, the technology innovation system has become global in many industries and requires firms to co-develop products with the most capable business partners and the most demanding customers wherever they may be located in the world. Manufacturers also have to locate some piece of their value chain near a critical mass of competitors to benefit from the diffusion of tacit knowledge through professional networks of scientists and engineers. Technonationalist policies do not work in globalizing industries because politically imposed constraints prevent domestic firms from accessing knowledge embedded in management, R&D, and manufacturing located outside domestic markets.

Globalization as the management of dispersed competence

In this volume, globalization is defined as "a set of processes leading to the integration of economic activity in factor, intermediate and final goods and services markets across geographical boundaries, and the increased salience of cross-border value-chains in international economic flows (Prakash and Hart, 1999)." We have chosen to focus on a more restricted meaning of the term "globalization" in this chapter because the broader definition does not provide the necessary explanatory purchase. At the individual firm level, we define globalization as the need to identify, access and coordinate capabilities located in a variety of geographic locales to produce a globally competitive product. Globalization in this sense is the opposite of the idea of building a local architecture of supply. Instead of insisting that all or most of the building blocks of a particular product (or service) be available

locally, the firm's top management team leverages these capabilities wherever they exist in the world. The needed inputs may include access to a world-class manufacturing facility to learn the demands that automation places on specific production tools or they may be intangibles like production engineering and process experience. In a globalized industry the managerial challenge involves coordination of the various aspects of the commercialization process, e.g. R&D, manufacturing and marketing that takes place in various countries.

Architecture of supply

One strand of theoretical work on industrial policy and international competitiveness stresses the continued importance of geography and geographic distance in limiting the diffusion of new technologies. This work emphasizes the importance of governmental policies designed to create and diffuse new technologies. One substrand of this literature focuses on the "architecture of supply" (Borras and Hart, 1994; Hart and Prakash, 1997).

According to this school of thought, international competitiveness is possible only when vital inputs are available to firms in a timely manner, in adequate amounts and at fair prices. To assure access to vital inputs, firms often locate their operations close to suppliers (or vice versa). Often, a few firms that are working to commercialize the same technology locate in the same region. Their suppliers tend to locate near them so that they can all take advantage of a common supply architecture. The idea of an architecture of supply is often used to explain the tendency of internationally competitive firms to locate specific activities in geographically concentrated in identifiable regions: e.g. Silicon Valley for semiconductor firms, Manhattan for international banks and investment firms, Prato, Italy, for high-fashion textiles and apparel firms, or Taiwan for laptop computer assembly firms. Since the supply architecture is built up around an innovating firm or group of firms, then these early entrants into the market may have an advantage associated with the difficulty of reproducing that architecture elsewhere.

The dynamics of supply architectures in globalizing markets

This notion of supply architecture, however, cannot incorporate an historically accurate picture of how firms compete in globally competitive industries. The domestic architecture of supply as described may be appropriate for the early stages of any new industry, especially high-technology industries. The rapid pace of change in the early stages of technology commercialization typically leads firms to cluster so that their managers and engineers can access networks through which tacit knowledge about product and process innovation flows.

Historically, multinational corporations granted considerable autonomy to their foreign affiliates and allowed them to establish their own local supplier and customer relationships without interference from headquarters. This strategy involved replicating domestic architectures of supply on a country-by-country basis. This method worked as long as industries were multi-domestic and competitors adopted a similar country-specific production and marketing strategy. However, with the increasing globalization of markets, managers discredited this strategy because it prevented firms from achieving economies of scale or scope (Kobrin, 1997). Now the managerial challenge for firms operating in global markets involves finding ways of maintaining close communication channels and coordinating their activities with both suppliers and customers as they become increasingly geographically dispersed.

This need to coordinate dispersed activities has given rise to what Borrus and Zysman (1997) call the "Wintelism" strategy of forming "cross-national production networks." Wintelism focuses on control over key technological standards rather than over production per se. A Wintelism firm will try to dominate its part of the market by pursuing a strategy to establish its product as the industry standard. It will then make information about technical standards available to firms that wish to develop complementary products, but it tries to maintain strict control and ownership over core technologies.

A good example of this would be the way in which Microsoft attempts to dominate the market for both computer operating systems and application software by controlling the graphical user interface via its Windows family of operating systems, while sharing information with smaller firms about how to write software that works well with the Windows operating system. Another example is the way in which Intel Corporation has dominated the market for microprocessors by quickly replacing one generation of microprocessor with the next, while also making available to both hardware and software firms information about how to make useful add-on products for computers incorporating their microprocessors. Borrus and Zysman (1997) call this a strategy of "open but owned" standards.

Wintelism has been internationalized as a result of the rise of cross-national production networks that US electronics firms adopted in response to competition from Japan. In cross-national production networks (CPNs), materials and components may be produced in one part of the globe and assembled in another. Sales and distribution of the goods may be in yet a third location. R&D and other related activities may be located in other countries. These activities can either be coordinated within a multinational corporation or through market transactions among providers of different parts of the value-chain. Wintelism strategies lead firms to create networked organizations able to leverage globally dispersed competencies without losing the flexibility to reconfigure their networks in response to new product generations or the introduction of product substitutes.

The success of these strategies may require the firm to adopt the following tactics (among others):

- 1 Building telecommunications networks or infranets to assure the timely exchange of detailed business and technical information among the cooperating entities.
- 2 Locating warehouses and service bureaus of supplier firms near where they are assembled into finished products so that the location where a particular tool or component is built becomes not important.
- 3 Providing timely feedback from assemblers to component manufacturers about problems of delivery or component quality and from component manufacturers to tool manufacturers about productivity problems with a particular tool.
- 4 Exchanging the best available market forecasts about shifting customer demand between component supplier and assembler entities.

We have discovered in the process of conducting field research on the global flat-panel display industry that precisely these practices have become commonplace in recent years. What we would like to do in the remainder of this paper is to show how this pattern of globalization changes the way national governments must think about their efforts to promote high-technology industries if they are to be effective in those efforts. We will illustrate this argument by looking at attempts by the US government to increase the participation of US firms at three points in the value-chains for flat-panel displays:

- 1 the development and commercialization of new tools;
- 2 high-volume manufacturing of displays; and
- 3 high-volume assembly of final products (in this case, laptop and notebook computers).

The global flat-panel display market

Although the primary application that drove the commercialization of FPDs has been laptop computers, other applications have proliferated over time. FPDs are used in personal digital assistants, digital cameras, rear projection TVs, Pachinko machines, small TVs, video cameras, car navigation systems, instrumentation and avionics systems. These applications include all sorts of flat panels, including super-twist-nematic liquid crystal displays (STN LCDs), thin-film-transistor (TFT) LCDs, electroluminescent (EL) displays, field emission displays (FEDs) and plasma display panels (PDPs). Table 5.1 shows breakdowns of demand for flat panels by type of end-use in 1997. The computer industry accounted for most of the demand for flat-panel displays, and primarily for use in laptop and notebook computers. After 1997, analysts project that flat-panel displays will be used increasingly as substitutes for CRT monitors for desktop computers (a much larger if slower growing market).

*Table 5.1. Market shares of flat-panel displays by major application, 1997
(in percentages)*

Computer	54.7
Consumer	21.2
Business	9.3
Industrial	7.6
Transportation	7.2

1997 Total Market=\$13.9 billion

Source: Presentation by Joseph Castellano, Stanford Resources, Inc., at Display Works '98, USDC Business Conference, San Jose, California, January 20, 1998.

The bulk of flat-panel displays sold from the 1980s to the present were LCDs. There has been a pronounced shift in demand away from the less expensive STN LCDs toward the higher performance TFT LCDs (Castellano, 1998; Young, 1998). One important factor in this shift is the reduction in prices of TFT LCDs as firms realize dynamic economies of scale, new manufacturers enter the market and new tools reduce the number of processing steps.

The Japanese flat-panel display industry

The main Japanese manufacturers of flat-panel displays are Sharp, Display Technologies Incorporated (DTI) (an IBM-Toshiba joint venture), NEC, Hitachi, Matsushita, Seiko-Epson, Optrex (a joint venture of Mitsubishi and Asahi Glass), Mitsubishi, Sanyo, Casio, Hosiden, and Fujitsu (see Table 5.2). Sharp has been the leader of this group since the beginning of LCD manufacturing in Japan. DTI is Sharp's main competitor and has surpassed Sharp in the production of large TFT-LCD panels for laptop computers. Sharp sells a wide variety of display sizes based on a range of liquid crystal display technologies so that its revenues from all LCDs exceed those of DTI (\$2.291 billion v. \$1.125 billion).

Hosiden has been the smallest, and possibly the weakest Japanese firm. Hosiden was an early innovator in TFT technology but had difficulty in making the transition to larger display sizes due to financial constraints. Hosiden lost its initial technical advantages to larger firms like Sharp and DTI. Philips of the Netherlands recently partnered with Hosiden to form a joint venture called Hosiden and Philips Display (HAPD) in order to satisfy Hosiden's urgent need for an injection of additional capital and Philip's desire to switch quickly from a double diode to a thin film transistor manufacturing process.

The supply architecture for flat-panel manufacturing is stronger in Japan than in any other country. All the necessary tooling and materials activities are located in Japan and at least one Japanese firm is in each activity. For example, (1) Asahi and Nippon Sheet Glass make glass substrates for flat panels; (2) Nikon and Canon make large-area scanners and

Table 5.2. Revenues of top LCD producers worldwide in 1997 (in millions of dollars)

Sharp	\$2,291
Toshiba/DTI	1,125
NEC	1,083
Hitachi	958
Samsung	700
Matsushita	667
Seiko-Epson	625
Optrex	458
Mitsubishi	450
Sanyo	425
LG	400
Casio	358
Hosiden	325
Fujitsu	300

Source: Presentation by Ross Young, DisplaySearch, Inc., at Display Works '98, USDC Business Conference, San Jose, California, January 20, 1998.

steppers for lithography; (3) NEC Anelva makes dry etching equipment; (4) Nitto Denko makes color filters and polarizers; (5) Dainippon Printing and Toppan Printing make advanced printing equipment for large-area flat panels; (6) Japan Vacuum Technology makes Indium Tin Oxide (ITO) films for transparent conductors; (7) Canon makes mirror projection systems; and (8) a variety of firms make fluorescent backlights. Even where Japanese firms are not strong, as in the manufacturing of liquid crystal chemicals, chemical vapor deposition (CVD) equipment, LCD driver chips, and high-performance glass, foreign firms headquartered their FPD businesses in Japan or entered into strategic alliances with Japanese firms to manage their global FPD business. Examples of this phenomenon include Merck Japan, Applied Komatsu Technology (AKT), Texas Instruments Japan, and Corning K.K.

The rapid growth of the Japanese flat-panel display industry was propelled by private firm investment, especially by Sharp. Sharp outsourced cathode ray tubes for its television sets and was determined to make its next-generation displays in-house.³ In general, Japanese firms' decisions to invest in FPD manufacturing facilities stemmed primarily from the importance of displays to their consumer electronics businesses. Managers in most Japanese FPD firms believed that display manufacturing capabilities were critical to their product differentiation strategies and that synergies existed between manufacturing displays and incorporating displays into final products such as notebook computers.⁴

Japanese government officials were, however, concerned that industry volatility would create economic instability and wanted companies to coordinate their investment plans to avoid massive surplus capacity accompanied by steep price reductions. Government officials were also concerned

with the inability of firms to agree on standard substrate sizes. This lack of standards resulted in high tool costs because tool developers had to develop entirely new products for each substrate size and could not sell enough of one sized tool to benefit from economies of scale.

The Korean display industry

The main firms in the Korean display industry are the big-three *chaebol* electronics firms – Samsung, Hyundai and LG (formerly called Lucky Goldstar).⁵ The *chaebols* are large, diversified industrial conglomerates that grew to their current size in Korea's heavy industrial expansion period. After building their own STN LCD production facilities, Samsung, LG and Hyundai decided in the mid-1990s to invest in TFT-LCD production facilities. Since they were late entrants into the TFT business, they invested first in second-generation manufacturing plants and then quickly moved to third-generation technologies by purchasing the necessary tools and engineering advice from Japan. They made these decisions largely on their own without extensive governmental assistance, viewing it as a way of capitalizing on earlier investments in integrated circuit manufacturing and a way of diversifying out of the increasingly competitive markets for standardized memory products (DRAMs).

Because of a perceived need to reduce dependence on Japanese production tools and to deal with problems of over-investment, the Korean government decided to involve itself in the organization of the industry and created a new organization called EDIRAK (the Electronic Display Industry Research Association of Korea). Through EDIRAK it could channel government research funds and build an industry consensus on future investments. The government did not have the power to impose its will on the firms, however, so despite a number of industrial promotion schemes, including funding of research and development through EDIRAK, the primary initiative for entry into the TFT-LCD markets remained with the firms themselves (Linden, Hart, Lenway and Murtha, 1998).

The incipient Taiwanese display industry

Because of the growing importance of the computer assembly business for Taiwan, the Taiwanese government and some of the larger firms have been considering major investments in the production of flat-panel displays for a number of years. In the Taiwanese government, the Industrial Technology Research Institute (ITRI) and ITRI's microelectronics research laboratory, the Electronics Research and Service Organization (ERSO), assumed leadership by creating a research laboratory for flat-panel displays and by trying to establish a series of research and production consortia to encourage investment in TFT-LCD production.

Prior to 1997, small Taiwanese firms like PrimeView and Unipac had built plants for producing STN displays and smaller TFT displays in relatively

low volumes, and larger firms like Chunghwa Picture Tubes (a subsidiary of the Tatung Group) had invested in STN displays. These firms held back from investing in the production of larger TFT display because of difficulties they had in forecasting market demand for different size displays while also coping with the considerable technological challenges posed by building current generation TFT plants. Taiwanese computer assemblers did not generally perceive a need for local suppliers of TFT displays, although they suffered somewhat during supply shortfalls of TFT-LCDs because display manufacturers tended to allocate scarce supplies to larger customers located in Japan and the United States (Linden, Hart, Lenway, and Murtha, 1998).

Beginning in late 1997, a number of Taiwanese firms announced their intention to invest in production of larger TFT panels for laptops and notebooks. Toshiba licensed its third-generation TFT production technology to the Walsin Lihwa Group, which includes Taiwan's third-largest integrated circuit firm, Winbond Electronics. IBM licensed its third-generation TFT technology to Acer Display Technology, the display subsidiary of Acer, Taiwan's largest and most successful personal computer manufacturer. The biggest challenge that Taiwanese firms face now is finding the number of engineers that they need to staff the new manufacturing facilities. Each new plant is estimated to require at least 200 engineers and operators. Currently, press reports suggest that there are only about 300 TFT-LCD professionals in Taiwan (*Commercial Times*, Taiwan, 19 February 1998).

The US display industry

The main US firms that invested in manufacturing flat-panel displays as of 1997 were: IBM, Motorola, Micron, Xerox/dpiX, Planar-Systems, Inc., Planar-Standish, Candescant Technology Corporation (CTC), Optical Imaging Systems (OIS), ImageQuest, Plasmaco, FED Corporation and 3-5 Systems. Except for the first four firms listed, all of these firms were relatively small. Of the smaller firms, Planar has primarily invested in electroluminescent displays and works jointly with dpiX to package TFT-LCDs for military avionics systems. OIS manufactures displays for military customers and is trying to use up its surplus manufacturing capacity by producing sensors for the medical imaging market. OIS does not have any immediate plans to invest in high-volume production. Plasmaco became Matsushita's plasma display panel R&D and production arm in 1996. Prior to that, the company manufactured monochrome plasma displays in small quantities. ImageQuest, a wholly owned affiliate of Hyundai, produced TFT displays for military end-users until December 1997 when Hyundai closed down the operation because of financial difficulties caused by the Asian financial crisis. 3-5 Systems specializes in smaller STN displays and will open an STN manufacturing facility in China in 1998.

US firms had some important strengths in flat-panel displays. In TFT display manufacturing, IBM was clearly the strongest because of its successful

joint venture with Toshiba. dpiX (a spinoff from Xerox) developed a very high-resolution display appropriate for the military, but too expensive for most commercial applications. US companies like Applied Materials, Corning Glass, and 3M dominated their segments of the FPD tool and materials markets.

With the exception of IBM and Plasmaco, managers of US FPD manufacturers believed along with US policymakers that it would be both possible and desirable for US firms to invest in commercial scale FPD manufacturing facilities in the US. Based in part on the US Defense Department's experience in revitalizing the semiconductor industry in the late 1980s, policymakers believed that if they could help build up the US supply architecture to match the one in Japan, commercial scale production would follow. We will discuss below how this perception permeated the policy debates from 1988 to the mid-1990s, and how it crippled US government efforts to help US firms compete.

The origins of US flat-panel display policy

US backwardness in display manufacturing first came to be a political concern in the late 1980s when the national debate over high-definition television began. When politicians and key industrial leaders realized that Japanese firms had assumed the role of technological leadership in both HDTV and flat-panel displays, they argued that Japanese leadership might eventually threaten US leadership in advanced electronics, particularly in computers. The Bush Administration was not disposed to promote specific industries, but in this case its hand was forced by the Democrat-controlled Congress to fund research in advanced displays, largely through the High Definition Systems program of the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense. From 1988 on, that program received annual allotments of around \$50–60 million for this purpose (Hart, 1994).

In the remainder of this paper we will discuss how US government intervention in the flat-panel display industry sprang from an inadequate understanding on the part of industry leaders, influential politicians and government officials of the requisites for building competitive enterprises in a global industry. Since many of the key technologies for LCDs were pioneered by US researchers, the inability or unwillingness of US firms to catch up with Asian firms was a cause of considerable puzzlement on the part of government officials. We will argue that this puzzlement stems from generalizing from previous successes in technology commercialization, especially in the semiconductor and computer industries when all the capabilities needed to develop a new technology were located in the US. To support our argument we will not only highlight the failures that are attributable to technonationalist excesses but also the successes that can be explained by the globalization-conforming strategies adopted by US firms

that successfully entered the global FPD market. One can see this clash between technonationalist and globalist perspectives in three main arenas: tools, display assembly and notebook assembly.

The US display consortium: tools in the United States

DARPA began funding research on FPDs in 1989 as part of the high-definition television program (DARPA, April 10, 1999). Officials in the Department of Defense argued that FPDs would be as integral to weapons systems as semiconductor chips and microprocessors. The most obvious applications involved replacements for the bulky and relatively short-lived cathode ray tubes (CRTs) in airplane cockpits, submarines, ships and tanks. The infantry of the future would also be equipped with head-mounted displays and wearable computers that would provide information about enemy location from a centralized information source. Soldiers would also carry rugged laptop computers into the field that would display important logistical, target and weapons status information and provide a communications link to command and control centers.

Despite both this financial support and a successful antidumping petition against Japanese FPD producers, which triggered steep antidumping duties on TFT-LCDs, in the early 1990s, the US FPD industry showed no signs of keeping up with their Japanese competitors. Both DARPA and industry leaders looked to the role that Sematech played in revitalizing the US semiconductor industry, for some of the answers about what they needed to do to help US FPD manufacturers develop the capabilities to enter the high-volume segment of the FPD market. One obvious problem that the FPD industry appeared to share with semiconductors was the need to establish and maintain a domestic supply infrastructure (Borrus and Hart, 1994). Sematech provided a model of how a public-private consortium would help to preserve an existing supply infrastructure that was having difficulty meeting the competition from Japan. It was not a very useful model, however, for demonstrating how to build an infrastructure from scratch.

In December 1992, DARPA sent out a request for proposals for a public-private consortium that would help the US overtake Japan's lead in FPD manufacturing. The consortium would facilitate development of the infrastructure of supply that would in turn provide the foundation for a commercially competitive US FPD manufacturing industry. Some of the consortium's supporters expected that flat-panel displays would become the same kind of technology driver for the US electronics industry that the semiconductor industry was in the 1970s. Others were more cautious in their appraisal of the potential growth and importance of the industry, but were willing to try to get the industry going in the United States anyway, especially if that would help reduce dependence upon importing and adapting Japanese commercial FPDs for military weapons systems.

In July 1993, DARPA helped to assemble a coalition of FPD manufacturers, including established companies such as Xerox, AT&T, and Texas Instruments, as well as smaller companies such as Optical Imaging Systems (OIS), Standish Industries, MagnaScreen, Photonics Imaging, Planar Systems and Plasmaco to create the US Display Consortium (Mentley, 1993). The consortium's mission was to facilitate the creation of a domestic FPD industry by establishing a common manufacturing platform for FPD production and developing technical specifications for the next generation of FPD production equipment (USDC, May 28, 1998). FPD manufacturers, suppliers and customers would contribute to this process by participating in road-mapping, benchmarking and standard-setting activities. The USDC hoped to attract members by pooling the costs of R&D, thereby reducing the risks associated with developing new technologies. DARPA provided \$20 million of the total of \$24 million in R&D expenditures for USDC projects in FY 1993 by slicing \$20 million off of the \$100 million allocated for HDS programs.

The USDC limited its membership to US-owned and controlled companies. Members had to have at least 50 percent US ownership. In order to interact directly with FPD tool and material suppliers, the USDC immediately organized this group into the SEMI-North American FPD Division. These suppliers (which also had to have at least 50 percent US ownership), could bid on USDC-sponsored development contracts. USDC rules specified that a USDC member would provide a beta site to help USDC equipment manufacturers integrate their tools into manufacturing lines. The USDC also organized other subgroups including: (1) the FPD Developers and Manufacturers (16 firms); (2) the Commercial Display Users Group (9 members); and the (3) the Military and Avionics Display Users (11 firms) (SEMI, April 9, 1997).⁶

Although DARPA provided \$20 million to get the consortium off the ground and promised subsequent follow-up funding, DARPA would have only one seat on the consortium's board of directors. Other board members included representatives of the staff, the display manufacturers, the display users and industry members. DARPA believed that industry leaders rather than government bureaucrats should establish priorities, set technology objectives and monitor progress. The governing board set general policies and made final decisions on the funding of projects. The technical board established research priorities, reviewed applications for funding, and made recommendations regarding which applicants should receive USDC contracts to the governing board. In addition to its governing and technical boards, the USDC had a small staff and a technical council.

Peter Mills, the former Sematech chief administrator, agreed to get the USDC up and running. By March 1994 the USDC had awarded their first development contract worth \$2 million to Photon Dynamics to develop a TFT-LCD visual test inspection system. In June 1994, the USDC awarded Lam Research a \$13.4 million contract to develop a dry etch system. The

USDC would provide about one-half the money needed to develop the tool and Xerox would help with process integration and testing the tool's performance in pilot production. Lam's CEO Roger Emerick promised to build a system superior to any other in the world (*Electronic News*, June 27, 1994). Lam had collaborated earlier with Sematech to develop the initial transformer-coupled plasma (TCP) technology for semiconductor production that, with USDC support, it would adapt for flat-panel display production.

The USDC did not restrict the sales of tools developed by its contractors to USDC members. As long as members got first right of refusal, USDC contractors could sell all over the world to help ensure the financial viability of their FPD business. In addition, USDC members decided that any intellectual property developed with USDC funding would belong to the company that did the work. Peter Mills commented that, "burdening them [materials and equipment companies] with legal requirements and royalty payments was not consistent with that goal [building a robust equipment and materials industry]" (Mills, 1995). DARPA did require, however, that firms that received USDC funding for a specific tool would have to notify the USDC and DARPA if they were planning to license their technology abroad.

DARPA renewed the USDC's funding in 1995, raising it to \$25 million. DARPA funding of USDC remained at the same level in FY 1996 but increased to \$60 million in FY 1997 when Congress added \$15 million to the \$45 million requested by the Clinton administration. The federal government was scheduled to reduce its participation to 50 percent as the consortium matured ("San Jose Selected . . . October 8, 1993). By 1998, the USDC had given out thirty contracts for a total of about \$90 million, one-half of which was funded by the development partner. Some of the initial project focus areas were: large-area chemical vapor deposition (CVD) tools, polymer coating, spacer technology, rapid thermal processing and laser annealing, automated handling of glass substrates, color filter manufacturing, and large-area lithography.

The USDC charged membership fees for belonging to the consortium according to the size of the firm: \$2,000 for firms with fewer than 100 employees, \$5,000 for firms with 100 to 500 employees, and \$10,000 for firms with more than 500 employees. Members were also expected to donate cash or equipment to offset the costs of running the consortium, and eventually to pay for 50 percent of the total costs. The matching funds came from the USDC development partners who had the responsibility for coming up with about 50 percent of the estimated cost of the tool development project. The company that provided the beta site for the tool was responsible for about 10 percent of the tool development costs, which could be deducted from its dues. This company also had the right to purchase the tool at an agreed upon "fair" market price.

Discussions among the membership to determine where to place the initial priorities were difficult because of the diverging technological

strategies of the small US display manufacturers. TFT-LCD manufacturers wanted to focus on TFT-LCD technologies, plasma manufacturers on plasma, etc. Eventually, a limited consensus emerged on developing manufacturing technologies needed for a wide variety of types of displays. The USDC tried to make decisions on a consensual basis and pursued development projects that reflected the technical needs of members engaged in each of the FPD technologies. In its deliberations, the USDC board also tried to take into account the interest of companies like Motorola and Micron, which were not USDC members.

While many important new technologies were developed with USDC financial support, very few of the USDC's development partners were companies that were global competitors in the FPD materials and tool markets. A number of major US firms who were successful in penetrating these markets in Japan and Korea opted not to participate in the USDC programs: most notably Corning Glass.⁷ The most important US-owned firm involved in flat-panel manufacturing, IBM, was also not included in any of the USDC's research projects. Interestingly, IBM joined the USDC Commercial Users Group, rather than as a manufacturer. This meant that none of the participants in the USDC programs benefited from the knowledge that could be obtained by working with high-volume manufacturers. To the credit of the USDC staff, this shortcoming was recognized early on and efforts were made to correct the situation, but unfortunately those efforts were not successful.

US–Korean cooperation in tools

Even before the Korean firms were successful in 1995 and 1996 in seriously challenging the TFT-LCD Japanese producers, the USDC began to debate the possibility of linking up their development programs with the high-volume producers in Korea. The political basis for this cooperative effort between US and Korean research consortia was in part the result of the Korean government's desire to reduce their companies' dependence on Japanese tools and in part the leadership exercised by Kenneth Flamm.

Flamm arranged a DoD mission to Korea in Spring of 1995 after receiving an invitation from the Korean government. DARPA staff members and other DoD staff members accompanied him on this trip. They visited all the major FPD manufacturers in Korea: Samsung, Hyundai, LG and Orion (a division of Daewoo that manufactured STN LCDs). According to Flamm, the South Koreans complained bitterly about the difficulty of purchasing color filters from Japan and paying very high prices for what they could get. They expressed concerns about getting access to other Japanese inputs in times of shortage. DoD had heard reports that MITI provided "administrative guidance" to Japanese materials and tool companies to assure that Japanese FPD manufacturers got first access to Japanese inputs.

When Flamm returned to the United States, he urged the USDC to get together with their counterparts in Korea. USDC finally agreed to pursue this in Spring 1996 after EDIRAK's leadership approached the leaders of the USDC at a Society for Information Display convention to inquire about the possibility of sponsoring joint research projects that would bring US tool producers together with Korean FPD manufacturers. This kind of cooperative effort would provide US tool developers with the access that they needed to high-volume manufacturing lines in order to ensure that their tools work well in high-volume plants.

By this time, however, Korean business representatives were not as worried about their dependence on Japanese suppliers as they were earlier. They told us that they had mostly good experiences in working with Japanese companies. Korean FPD manufacturers did not have confidence in US suppliers because very few of the latter had experience working with high-volume TFT-LCD producers and could not provide reliability guarantees. The Korean manufacturers' preferences were driven by the need to ramp up their manufacturing lines as quickly as possible to remain competitive with Japanese firms. They believed that success required working with tools that had an established track record in high-volume production.⁸

Despite the skepticism of the Korean firms, EDIRAK officials pursued the idea of reducing dependency on Japanese suppliers by working cooperatively with USDC. EDIRAK/USDC joint funding of projects was one result of the memorandum of understanding between the two organizations negotiated in the first part of 1996. Twenty-three members of USDC visited Korea in October 1996 to discuss possible collaborative efforts. Proposals for the first round of projects were due in April 1997.

Two projects were selected for joint funding in 1997. One went to the Accudyne Corporation to develop laser tools to cut substrates; MRS received the second grant to develop a new generation lithography tool. The failure of the lithography tool project to reach completion due to the decision taken by the MRS board to exit the FPD industry illustrates our argument about the negative impact of technonationalism on ability of the government to achieve its policy objectives.

The President and CEO of MRS, Griffin Resor, had succeeded over the course of about nine years in building a company with a very distinctive and leading-edge tool for stepping and repeating flat-panel display designs over the large areas required for competitive production of FPDs. MRS had received \$19.6 million from DARPA initially, and a \$9.5 million contract from the USDC in 1997 to develop a fourth-generation lithography tool. MRS was responsible for raising about \$5 million of the development costs of the new stepper. Under DARPA guidance, MRS used a special lens that was originally designed for military aerospace applications. The new tool was capable of stepping and repeating images of much higher resolution than those that could be obtained by using steppers designed for the

production of integrated circuits. Because of its potential for increasing both yield and throughput for large-sized TFT-LCDs, the MRS tool was of interest to some of the Korean high-volume producers, especially LG. As of mid-1997, before MRS received the USDC grant, a number of TFT-LCD manufacturers around the world had adopted the MRS stepper for use in their R&D pilot lines. By the end of 1997, the MRS stepper had been adopted in the manufacturing lines of only two low-volume plants in the United States.

As a result, MRS had no track record of working with a high-volume manufacturer. Therefore, it could not credibly answer questions from its prospective customers about such important issues as average "up time" of its machines, the mean time between failures, or the average speed with which it could process a substrate in a high-volume production line. There are a number of reasons why answers to these questions mattered to manufacturers. First, lithography accounts for a significant portion of total equipment outlays in a flat-panel display manufacturing facility. Steppers cost typically from \$2–4 million (MRS, 1997) per machine. They are used both for laying out the pattern of the pixels and thin-film transistors on the bottom plate of each TFT-LCD and for fabricating the color filters for the upper plate of the display. More importantly, the productivity of the entire factory depends critically on the reliability of lithography equipment. When a stepper is down, no new displays can be started. Using redundancy to control for low reliability in lithography adds greatly to the cost of production. While this potentially negative impact on productivity is not unique to steppers, steppers are among the most expensive of the tools used to produce flat-panel displays and are therefore seen by manufacturing engineers to be particularly crucial to the productivity of any given plant.

Because Korean firms were not first movers in TFT-LCD production, they were particularly eager to minimize their start-up costs. Given this, it was natural for them to opt to use tried and true Japanese tools from Canon and Nikon instead of the riskier tools available from US firms like MRS. Thus, for MRS to get a foothold in this market, it had to team up with at least one high-volume manufacturer, and, in the absence of governmental efforts to reduce risks, that manufacturer had to be willing to assume a higher risk than others in this crucial area.

As this logic became apparent to USDC and EDIRAK, they worked out a plan whereby a Korean manufacturer would be subsidized during the time that it acted as a beta site for MRS steppers. This subsidy was necessary to compensate the manufacturer for taking on additional technological risks and provide some assurance that its financial exposure would be within acceptable limits. However, a number of other problems cropped up in the attempts of USDC and EDIRAK to implement this plan. First, there was the question of whether US funds could be devoted to an enterprise for which a foreign firm would act as a beta site. This did not violate DARPA guide-

lines but USDC officials were concerned that the DoD officials responsible for the High Definition Systems program or the congressional committees charged with DARPA funding oversight might veto a US–Korean cooperative venture. Some DoD officials did not readily acknowledge that beta-siting the tool in a small US firm would not provide MRS the necessary process and performance information that it needed to build a globally competitive tool. EDIRAK and the USDC tried to solve these problems by arranging for MRS to enter into a strategic alliance with a Korean company that would be eligible to receive EDIRAK funding

Negotiations were well advanced to solve these problems when the Asia Crisis broke out and the plans had to be shelved. On March 31, 1998, the MRS board announced that the company was putting its USDC contract on hold and was redirecting its strategy towards the high-density printed circuit board interconnect market. We attribute this failure in part to the conflict between the basically nationalistic rationale for US R&D policies, especially those funded by the DoD, and the more “Wintelist” global strategies adopted by successful flat-panel suppliers and assemblers.

Successful US tool suppliers

In marked contrast with the USDC–EDIRAK story, US toolmakers like Applied Komatsu Technologies (AKT) and Photon Dynamics who have made it their business to service high-volume Japanese and Korean manufacturers have generally succeeded. While both companies were active in the USDC in its early days, both succeeded in their product development efforts through working directly with high-volume FPD manufactures. These firms are now solidly established in the industry. Any flat-panel display manufacturer that wants to be internationally competitive has to consider using AKT deposition tools and Photon Dynamics array testers, just as it has to consider Canon and Nikon lithography equipment.

Applied Materials entered the FPD businesses in 1991, two years before the creation of the USDC. When management attention of most US FPD companies was focused on protecting the US FPD industry from Japanese competition, Applied Materials was working with Japanese FPD manufactures to figure out how to improve production yields. In 1991, when representatives from Toshiba and Sharp first approached Applied Materials about adapting some of their semiconductor tools for FPD production processes, Sharp and Toshiba had first-generation production lines that achieved about 10 percent yields. These low yields stemmed in part from the use of equipment that had been developed to manufacture solar cell batteries, which were not harmed by particle defects. In contrast, for TFT-LCDs, particle defects caused the transistors that switched individual pixels to fail. If more than five pixels out of over a million were defective, then the display would not meet quality control requirements and would be discarded.

When Applied Materials first began to look into making FPD production equipment, Applied's engineers visited Sharp's and Toshiba's production facilities to learn about the manufacturing process. Based on their analysis, Applied decided to focus on chemical vapor deposition (CVD) tools because this was a key bottleneck in the production process. To develop the new CVD tool, engineers from Applied Komatsu Technology (AKT) worked closely with their counterparts at Sharp and Toshiba to develop new cluster process engineering techniques that both reduced particle defects and sped up the production process. Feedback from Sharp and Toshiba about materials and equipment performance was critical to their ability to develop the new tool. In order to get the data that they needed, Applied needed to work with a FPD manufacturer that was producing seven days a week, three shifts a day. Only with this kind of usage could AKT's engineers understand how to improve the CVD tool's reliability. During the development process, Toshiba and Sharp also sent their engineers to work at AKT. After AKT introduced its first CVD tool in 1993, FPD yields went from about 10 percent to about 90 percent. By 1994, AKT had the number one market share in Japan.

Applied's managers recognized that because most of their FPD customers were located in Japan, they would have to locate the headquarters of AKT there. The close proximity to their lead customers was important to ensure that AKT's managers had the best information possible about FPD manufacturers' strategies. Applied and Komatsu established the headquarters of AKT in Japan to get access to potential employees, but kept all of AKT's manufacturing and assembly in Santa Clara, California, in a facility dedicated to FPD CVD tool production.

Even AKT's extremely close relationships with its customers, however, did not keep its managers from making serious misjudgments about the rate of change from one generation of equipment to the next. Applied's managers had entered the FPD business thinking that it was like the semiconductor business and that substrate sizes like wafer sizes would remain constant over a relatively long period of time. Instead they found that in the FPD business substrate sizes grew quickly to increase display sizes and production efficiencies. Each increase in substrate size required significant engineering changes. This made it very difficult for Applied to enjoy the benefits of economies of scale and impossible to separate engineering from production. In order to anticipate future substrate size changes with more accuracy, AKT deepened its relationship with its customers, the display manufacturers and their customers, the laptop computer assemblers.

Photon Dynamics was established in 1986 to make integrated-circuit test equipment for gallium arsenide chips. When this chip technology did not expand beyond a small niche market, the company shifted its strategic focus to flat-panel displays. With DARPA support, the company refocused its strategy on developing test equipment using machine vision to detect

the faulty transistors that cause the pixel outages. The company received the first USDC research grant to develop its FPD inspection system. Its beta site partner for that contract was dpiX.

In reflecting back on the USDC contract, Photon Dynamic's CEO, Vincent Sollitto, described the situation near the end of the contract. By that time, Photon Dynamics had begun working on automation features which were a part of the USDC contract, but which were difficult to perfect because dpiX was running a relatively low-volume line that did not require automation. At that point, the USDC beta site coordinator at dpiX, who was also head of the oversight committee for the contract, agreed that Photon Dynamics had met its obligations to the USDC and signed off on the contract. Through this experience the company learned that the US customer requirements were so far removed from what commercial-scale users needed that USDC contracts were too much trouble for the money.

Photon Dynamics made the most progress in their tool development joint work with LG. Through this collaboration the company learned that it faced two major challenges in adapting its products for a high-volume fabrication facility; first, reducing particulates that cause the pixel outages that the machine was designed to detect and second, developing automation software that was compatible with the industry's standard automation software. Photon Dynamics and LG formed a joint task force to figure out how to reduce the particulate problem, which led to some relatively straightforward product design modifications. After the task force concluded its work LG ordered seven additional machines. In order to solve the software problem, Photon Dynamics stopped writing customized software, which it had begun to do during its first USDC contract for dpiX, and at significant expense hired programmers to develop a standard interface between the Photon Dynamics tool and high-volume automation systems for FPD production.

US government efforts to encourage high-volume manufacturing of displays

In February 1993, the chair of the Council of Economic Advisers, Laura D'Andrea Tyson, mentioned in a meeting with Robert Rubin, Chief of the National Economic Council (NEC), that she thought that, under the right conditions, the administration might want to intervene to help specific industries and that flat-panel displays might be a good example. After a briefing from industry executives and discussions with Rubin's staff, the staff of the NEC sent a memorandum to Tyson and John Deutch, the Deputy Secretary of Defense for Acquisitions, noting their agreement to do a study of the rationale, objectives and budget for a program for FPDs. Deutch then delegated the task to Kenneth Flamm, his Principal Deputy Assistant Secretary for Dual-Use Technology Policy and International Programs (Carey, Young and Burrowes, 1994).

Flamm assembled a task force of people from a variety of government agencies: Defense, Energy, Commerce, Treasury and the CIA. Flamm, along with his deputy for dual-use technologies, Richard Van Atta, coordinated the work of the task force and briefed members of the National Economic Council (NEC) on a regular basis. Van Atta personally visited most of the FPD manufacturers in the United States, while Flamm received visits from firm representatives in his Washington office. Task force members conducted interviews and meetings with business representatives both in Washington and in the field in order to gather relevant information. The initial drafts of the final report were done by various task force members from different agencies.⁹ A final report was to have been made public after the April 1994 announcement but was not released until late September 1994 (DoD, 1994).

Flamm announced a new initiative to promote the advanced display industry on April 28, 1994, which he called the National Flat-Panel Display Initiative (NFPDI). Flamm said the government would spend \$587 million over five years on it (see Table 5.3). DARPA funding would be increased from \$46 million in fiscal year 1994 to \$68 in the next four fiscal years. Another \$199 million was to be transferred from other government programs, including the Technology Reinvestment Project (TRP).

In addition, \$50 million would be allocated for building a second TFT-LCD manufacturing test bed. DoD funding for a second manufacturing test bed was motivated by the political success of the Michigan congressional delegation to insert a paragraph in a budget appropriation act authorizing federal funding of a pilot manufacturing facility for the production of TFT-LCDs. The paragraph was worded in such a way that only one firm, the Michigan-based OIS, could possibly qualify for the funding.

When officials in the DoD saw the paragraph in the marked up version of the appropriations bill, they saw that the funding of OIS could be interpreted as a direct subsidy and hence might violate US treaty obligations under the GATT (now called the World Trade Organization). The paragraph was rewritten so that the allocated funds would be used to fund research and development (R&D) and not production and that there would be some sort of competition for the funds, but the language still gave an enormous

Table 5.3. Department of Defense FPD funding plan (in millions of dollars)

	FY94	FY95	FY96	FY97	FY98
Core R&D	46	68	68	68	68
Manufacturing Test Bed	50	0	0	0	0
R&D Incentives	0	25	50	50	74
Purchase Incentives	0	10	10	TBD	TBD
TOTAL	96	103	128	118	142

Source: Photonics Spectra, June 1995; DoD is the original source.

Note: TBD means "to be determined."

advantage in any competition to OIS. As a result, the NFPDI included an additional \$50 million in funding from ARPA to pay for a second TFT-LCD pilot plant. The competition for this second plant was won by a consortium of firms that included Xerox, AT&T and Standish Industries.¹⁰

A policy decision was made to spend funds authorized by Title III of the amended Defense Production Act (1992) for the insertion of new technologies into military systems. The problem that this decision was designed to solve was that acquisitions officers in the Department of Defense were required to "qualify" new technologies before they could be inserted into new or existing military systems. This was not required by law, but evolved simply as a prudent practice. The costs connected with qualification were usually borne by the defense contractors, but if not, they had to be paid out of program funding, which was a major disincentive for using new technologies, especially those commercialized by small firms that could not afford the costs of qualification. The NFPDI outlined a policy decision to allocate a portion (\$30 million) of Title III funds for the qualification of TFT-LCDs for insertion into military systems. The same Michigan delegation members who supported the funding of OIS in the appropriations bill also supported the use of Title III funds to qualify TFT-LCD displays for insertion in military systems. About \$6 million of the \$30 million would go to Allied Signal Corporation to qualify OIS TFT-LCDs for use in the former's Apache helicopter program.

The Department of Defense was quite proud of the new insertion program because they thought the small amount of spending for qualification expenses would succeed in opening up much larger military and civilian markets to US display firms. The unanticipated consequence of this program was that it discriminated against other display technologies such as CRTs and field emission displays which DARPA was also supporting and which were expected to compete for some of the same military applications. Some of the funds paid for the qualification of TFT-LCD displays produced in whole or in part by foreign-owned companies.

A third part of the NFPDI was the funding of display technologies under the Technology Reinvestment Project (TRP). The TRP originated in proposals by Senator Jeff Bingaman (D, New Mexico) in the early 1990s. Bingaman's proposals included funding for R&D consortia, outreach programs to help defense firms diversify into commercial markets, manufacturing extension centers to help diffuse existing technologies and best practices to US manufacturers, and regional technology alliances to promote the restructuring of defense-dependent regional economies (Stowsky, 1996, p. 13).

The Clinton administration embraced Bingaman's idea, in somewhat expanded form, as its response to the problem of "defense conversion" – reducing the negative economic effects of military downsizing in the wake of the end of the Cold War. On March 11, 1993, Clinton announced the TRP in a speech to the employees of the Westinghouse Electronic Corpor-

ation in Baltimore. The main idea behind the TRP was to use the concern over defense conversion to justify the channeling of new R&D funds through DARPA to the defense community. The TRP was to ramp up quickly from around \$70 million in the first year to over \$500 million in its fifth year.

The DoD was thus to be the main source of funding for the NFPDI, but a small amount of additional support would come from the Departments of Commerce and Energy. Funding of proposals would be competitive and would be disbursed through “agreements” rather than grants or contracts.¹¹ According to Flamm, the flat-panel initiative would be “technology neutral. . . . We have no priority technologies. We are not picking technological winners here . . . if the technology changes, the program will have the flexibility to go with where the technology is moving” (Andrews, 1994; Bradsher, 1994a; Bradsher, 1994b; Gomes, 1994).

The flat-panel initiative was linked to a larger policy change in the area of “dual use technology”: the Clinton Administration has developed a new technology strategy that promises to deal effectively with these major changes affecting our national and economic security in the 1990s. That strategy includes the dual use technology vision outlined by Secretary of Defense William Perry and Deputy Secretary of Defense John Deutch. At the heart of this vision are two key principles:

- To reduce costs, and accelerate the introduction of new technologies into defense systems, DoD must make use of components, technologies and subsystems developed by commercial industry, wherever possible, and develop defense unique products only where necessary.
- To capitalize on this acquisition strategy, DoD’s R&D efforts must focus on critical dual use technologies and capabilities that will continue to be advanced through industry’s efforts to remain competitive in commercial markets. Thus, even where the military applications are specialized or unique, the underlying technologies will be sustainable through commercial forces (DoD, 1994, p. I-1).

The report argued that the flat-panel display technologies were “critical dual use technologies.” The initiative also included a production target for the US flat-panel display manufacturing industry:

This study judges that penetration of 15 percent of the world market (up from the current 3 percent) is both an achievable near-term goal and an appropriate point at which to consider whether a government flat panel display program should be redefined, reduced, or terminated. This level of market share is probably sufficient to nurture and sustain the *critical mass of U.S. infrastructure suppliers needed for the long term success of the U.S. FPD industry* [emphasis added], to permit industry to exploit continued government R&D investments in advanced display technology, and to satisfy DoD needs at acceptable costs.

(DoD, 1994, pp. I-7 and I-8)

This paragraph is at the heart of our argument that the NFPDI was motivated by technonationalism.

After the Republicans won control of the Congress in the 1994 elections, the Congress voted to cut spending on the TRP, the dual-use policies of the Clinton Administration came under attack, and the NFPDI lost its strongest advocate, Kenneth Flamm. Flamm returned to the Brookings Institution in September 1995 to finish a book on the semiconductor industry he had been working on prior to joining the Clinton Administration. His departure was also motivated partly by the desire to avoid fighting continuous battles with Congress to cut back the funding of the NFPDI and to abandon the administration's dual-use policies. The deep cuts in the TRP meant that the \$199 million that was supposed to be spent on focused R&D incentives out of the planned total of \$547 million for the initiative was reduced to \$25 million (see Table 5.3). Any hope of subsidizing a high-volume flat-panel manufacturing plant in the United States died with the TRP cuts. Although the ARPA High Definition Systems and USDC efforts continued with considerable Congressional support after 1994, the orphaned NFPDI faded into the background.

DARPA funding for US production test beds did not result in US investments in high-volume production. The absence of US high-volume production created serious obstacles for USDC development partners who were constrained to beta-site their tools with US companies. Both OIS and dpiX steadily worked to build up their sales through military contracts and targeting the avionics and medical imaging markets. OIS produced only about 40,000 displays annually at peak capacity (compared with 1.5 million units produced annually in high-volume plants in Asia). DpiX, the Xerox FPD spin-off, competed head on with OIS in the avionics and medical imaging markets. They produced less than 80,000 units a year. This was more than enough US-production capacity to meet military demand for high-performance displays but not enough for the firms involved to be able to compete with Asian firms for commercial applications. OIS, especially, struggled with getting its yields up and took a long time to before it could fill its orders. Malcolm Thompson, CEO of dpiX, focused on developing very high-quality displays with vivid colors, wide viewing angles and clear video pictures. These displays, however, cost about \$10,000 for a 19" display which would have cost around \$4,000 from a high-volume manufacturer at that time.

The lack of formal relationships with high-volume manufacturers may explain the relatively slow progress that US producers (with the notable exception of IBM) were able to accomplish. A focus on low-volume production of mostly military displays prevented US manufacturers from taking advantage of the tacit knowledge that flowed through the networks of high-volume notebook manufacturers and their suppliers that helped managers in Asia to anticipate market shifts and allowed engineers to figure out how to solve process problems. IBM, the one US company with

high-volume production facilities through its strategic alliance with Toshiba, had access to these networks, in part because the company chose to locate its FPD manufacturing facility in Japan, but mainly because it decided from the outset to take the risk of investing in high-volume production.

The mystery of IBM's nonparticipation in US promotional efforts

One of the puzzles we confronted when we undertook field research on the NFPDI was why IBM, the strongest US firm in the TFT manufacturing area, was not a central participant in the USDC or a beneficiary of any of the NFPDI programs during their short life span. We asked this question in interviews with both government officials and representatives of the firm. The answer was surprising.

Most of the government officials we spoke to were themselves somewhat surprised at the nonparticipation of IBM, while also sharing some of the common stereotypes about the nature of IBM's investments in this area. There was considerable confusion about the nature of the joint venture between IBM and Toshiba and how the responsibility for building the FPD business that IBM originally gave to their Japanese affiliate contributed to the competitive strength of the entire corporation.¹²

IBM originally developed an interest in entering the FPD business because of its stake in the computer monitor business. The company recognized that CRT might become obsolete if inexpensive flat-panel displays could be developed and that high-quality displays were an important contributor to the perceived value of computers. IBM wanted a manufacturing presence in whatever technology might replace or supplement CRTs for computer monitors. In the mid-1980s, IBM worked on gas plasma displays, but exited the plasma business because the plasma displays of that time were monochrome, too heavy and consumed too much energy for portable applications. They sold their plasma plant in New York state to a group of investors who formed Plasmaco (see the Plasmaco story above). When IBM engineers looked at Matsushita's portable TVs with color TFT-LCD screens they saw the technology's potential and redirected their efforts towards this technology.

In a departure from traditional norms, from 1996 to 1988, IBM entered into an R&D alliance with Toshiba. Engineers from both companies spent the first year of the alliance working in Toshiba labs and the second year working in an IBM Japanese research facility in a clean room constructed specifically for the project. This alliance produced two 9.5" prototype displays in 1987 and a 14" TFT-LCD prototype in 1988. The 14" prototype sufficiently impressed IBM's top management that they decided to go ahead with manufacturing.

IBM's monitor group in Raleigh, North Carolina, submitted a proposal to take on the manufacturing responsibilities for IBM's TFT-LCD business.

Jim McGroddy, the senior IBM official responsible for making the location decision did not want to give this responsibility to the monitor group because he was afraid that they would sit on the technology in order to protect their CRT business. Given IBM's financial constraints at the time, he also decided to extend the research relationship with Toshiba and create a manufacturing alliance that would use many of the same engineers who worked on developing the prototype. By leveraging their experience, McGroddy believed that IBM would ramp up production relatively quickly and with much less expense than would be involved in training an entirely new group of engineers. The IBM/Toshiba joint manufacturing venture, Display Technologies Incorporated, began production in 1991.

In 1992, before the NFPDI, when DARPA was struggling to figure out how to encourage US production, IBM expressed a willingness to license DTT's technology to a manufacturing consortium put together by AT&T and Xerox. IBM officials reported that DARPA did not like the idea of paying royalties to an entity located in Japan and was reluctant to fund the project. AT&T became frustrated with the politics involved in obtaining government funding and decided drop the DARPA project and entered into an alliance with a Japanese company that would transfer its FPD process engineering expertise to a US production facility.

AT&T set up a pilot line at Bell Labs and used it to develop process engineering techniques. After an agreement with a Japanese firm fell through, the company approached LG, which expressed a serious interest in forming an alliance. In 1996, just after AT&T split into three companies, Bell Labs abruptly terminated the project as part of its effort to cut its expenses before it was spun off as a part of Lucent Technologies. In the interim, AT&T had joined with Xerox and Standish in one of DARPA's production test beds while it was working on its pilot line. To meet its obligations in the DARPA project, AT&T did not have to manufacture displays. Instead it could meet the terms of the contract by working on techniques for attaching driver chips to displays in its Princeton lab.

The global notebook computer industry

The need for FPD manufacturers and tool suppliers to locate some of the key managerial and technical functions close to the heart of the industry does not appear to extend to computer assemblers. Notebook computer assemblers try to obtain components from the best component producers no matter where they are located. They do not require that component manufacturing take place near their assembly plants, but only that the supplier locate a warehouse and service facility nearby so that "just in time" or lean production techniques can be used. This is precisely the behavior that was described to us by representatives of two important notebook assemblers: Compaq Computers in Houston and First International Computer in Taiwan.¹⁵

During the period leading up to the announcement of the NFPDI, DOD analysts argued that US dependence on Japanese FPDs could compromise US economic and political security. They argued that the threat to US economic security would result if US computer assemblers like Compaq could not sell their computers because in times of shortage Japanese FPD manufacturers would allocate displays to Japanese computer assemblers, especially their internal computer units, first. During these periods, Japanese computer assembly companies would use this preferential access to displays to wrest market share away from their US competitors.

Instead, we learned in our interviews that although FPD manufacturing capabilities may provide their in-house computer assembly units some advantages, the competitive strength of computer assemblers stems from more than just these manufacturing strengths. Our research indicated that, instead, the display manufacturing subsidiaries of vertically integrated companies behaved as much as possible like merchant suppliers of displays, insisting on their right to sell displays on the open market. Notebook assembly subsidiaries similarly insisted on their right to buy displays on the open market as well as purchasing them internally. The main reason for this was the need of both suppliers and assemblers to use the merchant market as a benchmark for price, quality and consumer demand, and as a check against the tendency of purely captive producers to ignore changes in the competitive environment.

Computer assembly firms like Compaq and FIC, with no internal supplier of displays, were somewhat disadvantaged relative to more integrated firms like IBM and Toshiba because they could not dictate the design of a new display to their suppliers, although they could try to use their buying power to be persuasive. For example, IBM were able to introduce a 12" TFT-LCD display into their Thinkpad notebook computers before their competitors in part because they could source their displays from a new DTI manufacturing line. DTI's risky move left their competitors with non-economic production facilities that were not optimized for 12" displays. These companies were at a competitive disadvantage until they built new third-generation plants optimized for larger display sizes.

Thus, timing is of the essence and it is not entirely clear that an assembler with a captive display supplier will have any advantage in timing over an assembler who purchases displays on the merchant market. The success of both depends upon their ability to anticipate market trends or respond quickly to the first movers' product innovations. More than manufacturing capabilities, this required FPD manufacturers to track the product preferences of their leading customers, which were not necessarily their internal customers, and to benchmark price, quality and consumer demand. This also required computer assemblers to understand a component's trajectory so that they could design next-generation components, in our case, a larger display size, into their flagship products in a timely manner.

To compete with IBM, Compaq and FIC used different strategies to ensure their supplies of the most advanced displays. Compaq leveraged the competition among its suppliers to enhance its buyer power. Compaq also always tried to have at least two suppliers for a given component, and used its quantity purchases to transform each component into a standardized product to reduce its need for retooling and to keep prices down. The managers of FIC used personal networking to learn about technological developments in components as a reality check against announcements by marketing divisions about intentions to ship new products. They also used these networks to build trust relationships with their suppliers. These relationships were in part based on their willingness to buy extra displays in times of surplus in exchange for an assured allocation in times of shortage.

Summary and conclusions

We have argued in this paper that economic globalization affects the efficacy of both firm strategies and government policies. Firm strategies and government policies motivated by technonationalism will generally fail to achieve their stated goals in globalizing markets. Those consistent with a globalist stance of openness to the world, of flexibility in the choice of technologies and industrial partners, and of readiness to go anywhere to obtain the necessary market information, intellectual property, key personnel, and critical components are much more likely to succeed. Success, in this case, is measured in terms of international competitiveness of national firms.

In this chapter we have used the experience of IBM, Applied Materials, Corning Glass and Photon Dynamics to illustrate the kinds of global strategies on which firms can build this success. These firms did not rely on government subsidies and worked with their most demanding customers to develop world class products. IBM, Applied Materials and Corning Glass headquartered their FPD businesses in Japan to track the rapid changes taking place in the industry. Their manufacturing, R&D, and marketing were dispersed throughout the world, including the US. By locating key managerial and technical operations in Japan, these companies were able to achieve one of the policy objectives identified by technology policy analysts; the development of FPD infrastructure companies that would build a dominant position in the global flat-panel display market.

The competitive strength of these companies also contributed to US economic strength. Applied Komatsu's sales in Japan created jobs in Santa Clara California where the CVD tools were assembled. DTI created lots of R&D projects for scientists and engineers at IBM's Watson Labs in New York. Corning Glass did all the R&D for its new FPD glass products in Corning, New York. But without its sales force in Japan, the researchers in Corning would not have had a very clear idea about how to focus their

efforts. These firms' abilities to manage these dispersed competencies ultimately created more high-value-added jobs in the US.

These firms also participated in "Wintelist" networks that required a relatively high degree of openness either through licensing or some other form of open exchange of information. In the FPD case, we saw IBM working with Toshiba to tackle development and production problems. This alliance provided both companies with sufficient leverage to set *de facto* industry standards, especially after DTI began producing 12" displays. DTI also worked openly with Applied Materials to develop a CVD tool that would raise yields and productivity levels for the entire industry. There was no economic way that DTI could develop a proprietary CVD tool for itself and withhold its advantages from competitors. DTI's partners would have to develop new product and marketing strategies to leverage any strategic advantage that they built during their early experience with the tool.

While the FPD case clearly illustrates the limits to technonationalist policies and their incompatibility with the global technology innovation system, questions still remain about what political changes have to occur before government policies reflect these limits. Will the US government and US taxpayers accept the fact that if their goal is to support the development of the best new technologies, US public funds will have to flow to non-US companies? Or will a knee-jerk "buy American" spirit continue to shape governmental funding strategies. For US technology policies to be truly effective, they must be accompanied by a spirit of openness to foreign participation in domestic technological efforts – a spirit that was there at the beginning of the NFPDI but that got lost as time went on – and must eschew the narrow nationalism that unfortunately seems to come with the coalition building required to support funding of such efforts.

The spirit of openness is beginning to be seen in older R&D programs like Sematech in the United States and the Fifth Generation Computer Project in Japan (Mathews, Cho and Cho, 1999). One can view the efforts in the United States and Korea to create a favorable political environment for USDC-EDIRAK cooperation also as a step in the direction of openness. But the most direct way to improve the long-term prospects of domestic firms in globalizing industries via public policy is to support, wherever possible, the efforts of individual firms and groups of firms to develop new technologies and new products that are globally competitive. Wherever technonationalism gets in the way of this, it has to go.

That leaves open the question of how to foster the spirit of openness that is the key element of what we call globalism. For internationally competitive firms and their managers, internationalization strategies are a response to the pressures of competing in an increasingly globalized market. Firms that are insulated from international competition, for whatever reason, are less likely to copy these strategies or to have a globalist spirit. To the extent that defense-oriented firms are insulated from

international competition, they will remain in the technonationalist camp. Similarly, defense agencies that work primarily with such firms will also tend to be technonationalist. The only way out of this bind, in our opinion, is to encourage defense agencies to do more of their business with internationally competitive firms. It is our view that they will catch the globalist spirit by doing this. That leaves, however, the problem of how they can convert their natural constituents in Congress and the federal bureaucracy to globalism. What is needed is a way of redefining national interests in an age of economic globalization. We offer this case as one of a growing number that might serve as the basis for such a redefinition.

Notes

- 1 This is a revised version of a paper that was prepared for delivery at a conference on "Coping with Globalization," sponsored by the Center for the Study of Global Change of Indiana University (with contributions from a number of other sponsors) and held in Alexandria, Virginia, July 31 – August 1, 1998. Research for this paper was made possible by a grant from the Alfred P. Sloan Foundation. Research assistance for this paper was provided by Craig Ortsey. Please do not cite or quote without the written permission of the authors.
- 2 We shall demonstrate below that the conventional view was not completely accurate since a number of both US-based and European firms were major participants in display markets.
- 3 Interview with Sharp managers in Kobe, Japan, on June 6, 1997.
- 4 Interviews with managers of Japanese firms in November 1996 and June 1997.
- 5 A fourth *chaebol*, Daewoo, had investments in STN-LCD production and was attempting to become a global competitor in consumer electronics. Daewoo had not invested in TFT-LCD production as of 1997, but was investing in other advanced display technologies. We were unable to include Daewoo in this study.
- 6 The USDC said that there were 125 members of the SEMI-FPD Division of SEMI in a contemporary document but not all of these were members of the USDC.
- 7 The USDC had agreed to provide matching funds to Corning Glass to build a finished glass facility in the US. As of 1997 all of Corning's FPD glass was finished in Shizuoka, Japan. FPD producers located in the US that use Corning's glass pay a small duty on imports of finished glass from Japan. Even with the matching grant, Corning decided not to build the facility because the US FPD glass demand was so small that it could not meet internal rate of return targets.
- 8 Confidential interviews with US government officials in Washington DC, December 1995.
- 9 Interviews with Kenneth Flamm and Tom Kalil on December 18, 1995; and interview with Richard Van Atta on December 19, 1995.
- 10 Interviews with US government officials in Washington, DC, December 1995.
- 11 The designers of the program wanted to have more flexibility in funding than was possible through grants – where the recipient has no obligation to deliver anything to the government – and contracts – where the contractee has to pre-specify a deliverable and is penalized for not providing it in a timely manner. Interview with Richard Van Atta on December 19, 1995.
- 12 Interviews with IBM and DTI managers on July 22, 1996; November 6, 1996; and June 2, 1997.
- 13 Interviews with Compaq managers on March 26, 1997 and FIC managers on May 26, 1997.

Bibliography

- Andrews, Walter (1994) "U.S. revamps FPD support to fuel industry," *Electronic News*, May 2, p. 1.
- Borrus, Michael and Hart, Jeffrey A. (1994) "Display's the thing," *Journal of Policy Analysis and Management*, 13, 1: 21-54.
- Borrus, Michael and Zysman, John (1997) "Globalization with borders: the rise of wintelism as the future of global competition," *Industry and Innovation*, 42, 2: 141-66.
- Bradsher, Keith (1994a) "U.S. to aid industry in computer battle with the Japanese," *New York Times*, April 28, p. 1.
- (1994b) "Pentagon tests new policy in subsidizing an industry," *New York Times*, April 28, p. C1.
- Business Wire*. "San Jose selected as site of flat panel display consortium," (October 8, 1993). Accessed via Nexis/Lexis.
- Carey, John, Young, Dori Jones and Burrowes, Peter (1994) "Why Washington is anointing flat panels," *Business Week*, May 16, p. 36.
- Castellano, Joseph (1998) Presentation delivered at Display Works '98, USDC Business Conference, San Jose, California, January 20.
- DARPA (Defense Advanced Research Projects Agency) (1999) *High Definition Systems (HDS)*, available HTTP: <http://www.darpa.mil/MTO/Displays/HDS/Facts.html>.
- DoD (Department of Defense) (1994) *Building U.S. Capabilities in Flat Panel Displays: Final Report of the Flat Panel Display Task Force*, Washington, D.C. Available HTTP: <http://www.acq.osd.mil/es/fpd/fpd01.html>.
- Gomes, Lee (1994) "White House promises another \$300 million for flat panels," *San Jose Mercury News*, April 29, p. 1E.
- Hart, Jeffrey A. (1994) "The politics of HDTV in the United States," *Policy Studies Journal*, 22, 3: 213-28.
- Hart, Jeffrey A. and Prakash, Aseem (1997) "The decline of 'embedded liberalism' and the rearticulation of the Keynesian welfare state," *New Political Economy*, 2, 1: 65-78.
- Kobrin, Stephen J. (1997) "The architecture of globalization: state sovereignty in a networked global economy," in John H. Dunning (ed.) *Governments, Globalization and International Business*, Oxford: Oxford University Press.
- Linden, Greg, Hart, Jeffrey, Lenway, Stefanie and Murtha, Tom (1998) "Flying geese as moving targets: advanced displays in Korea and Taiwan," *Industry and Innovation*, 5, 1: 11-34.
- Mathews, John, Dong-Sung Cho, and Tong-Song Cho (1999) *Tiger Technology: The Creation of a Semiconductor Industry in East Asia*, Cambridge: Cambridge University Press.
- Mentley, David E. (1993) "The Launch of the United States Display Consortium," *Electronic Display World*, 13, 7: 21-5.
- Mills, Peter (1995) *Solid State Technology*, Accessed via Nexis/Lexis.
- MRS (1997) *Annual Report*.
- Prakash, Aseem and Hart, Jeffrey A. (1999) "Globalization and governance: an introduction," in Aseem Prakash and Jeffrey A. Hart (eds), *Globalization and Governance*, pp. 1- 24, London: Routledge.
- Semiconductor Equipment and Materials International (1997) "No Title," available HTTP: <http://www.semi.org/Focused/fpd/usdc.html>.

- Stowsky, Jay (1996) "America's technical fix: the Pentagon's dual use strategy, TRP, and the political economy of U.S. technology policy," paper prepared for the Council on Foreign Relations, New York, February 23.
- USDC (United States Display Consortium) (1998) "No Title," available HTTP: <http://www.usdc.org>.
- Young, Ross (1998) Presentation delivered at Display Works '98, USDC Business Conference, San Jose, California, January 20.