# The Consumer Electronics Industry And the Future Of American Manufacturing

## How the U.S. Lost the Lead And Why We Must Get Back In the Game

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# Executive Summary

The United States has been losing ground in manufacturing-first in the "mature" industries and then in the high-technology industries which were supposed to be our future. Among the high-tech sectors, the first to go was consumer electronics, conceded as "lost" by most observers in the mid-1970s. The loss of consumer electronics is particularly significant; the strong competition in this industry provides a major source of demand for new manufacturing technologies to support high-volume, rapidly changing designs. These new product and process technologies, such as those exemplified by high definition television (HDTV) and the increased use of chip technology to replace functions previously carried out by electrical and mechanical devices, are crucial to the future of American manufacturing.

**Consumer electronics. . .** ***provides a major source of demand for new manufacturing technologies to support high-volume.***

The failure of many U.S. firms to compete in high-volume, fast-turnaround consumer electronics products exemplifies a basic weakness in the management of technology within firms. One cause of this weakness is the creation of a management culture oriented toward low-volume production for the defense industry. Defense procurement practices emphasize design and production methods-low-volume, design redundancy, and high costs-that are not highly rewarded in the civilian marketplace.

The Department of Defense (DOD) is directly responsible for the bulk of U.S. research and development (R&D) expenditures (accounting for 68.4 percent of all U.S. R&D in 1987). U.S. per capita defense expenditures, now about $1,200 annually, are six times the rate for Japan. For nearly a decade, the nation's budgetary priorities have emphasized greatly increased defense spending, making the defense sector even more attractive to U.S. firms. This has created "safe havens," where there is little international competition, for U.S. high-technology firms.

***Defense spending...has created "safe havens," where there is little international competition, for U.S. high-technology firms.***

By contrast, their Japanese counterparts have generally had to rely on high-volume, fast-turnaround consumer markets to spur growth, which required them to develop sophisticated design and manufacturing techniques for rapidly changing, highly competitive environments. As a result, high quality, low costs, and short cycles for product development have become the hallmarks of Japanese production and have been largely responsible for the tremendous success that Japanese firms have enjoyed in a wide range of consumer and industrial products.

A related cause of U.S. competitive weakness in consumer electronics is the focus in the U.S. on short-term profitability. This unwillingness to invest in the longer term and to support more risky R&D programs which are not backed up by the DOD has led to the failure of many companies to position themselves in key new technologies such as HDTV.

*Many countries have come to view strategic alliances between domestic firms as an effective institutional mechanism for developing new technologies.*

Many countries have come to view strategic alliances between domestic firms as an effective institutional mechanism for developing new technologies as well as for commercializing them. These alliances recognize the extremely rapid maturation of the production processes dominated by today's high technologies and the common need among manufacturing firms to accelerate the speed of development, as well as the integration of diverse technologies.

A recent attempt to formulate this kind of coordinated program in the United States is an initiative spearheaded by the U.S. Department of Defense in response to the deteriorating commercial and technological state of the U.S. semiconductor industry. In the name of national defense, the Defense Advanced Research Projects Agency (DARPA) and the DOD are attempting; to prevent any further erosion of the U.S. commercial manufacturing base in critical new technological areas such as semiconductor manufacturing and HDTV. Such government initiative is unprecedented in U.S. history and seems clearly a forerunner of new policy initiatives, which if they are to be successful, must be targeted at civilian markets.

*Shared manufacturing may be one of the ways to upgrade the manufacturing capabilities of smaller firms without the risks associated with licensing new technology.*

Other new efforts will have to include investment in the basic science and engineering infrastructure as well as focused efforts to improve the broad-based manufacturing capabilities of American firms. While some progress has already been made in the nation's largest firms, many small- and medium-sized firms have neither the capital nor human resources to improve their own production facilities, and are forced to license their technology to potential competitors. Shared manufacturing may be one of the ways to upgrade the manufacturing capabilities of smaller firms without the risks associated with licensing new technology.

## How the U.S. Lost Consumer Electronics

In just 20 years the United States has gone from the world's leading producer of electrical and electronic goods to a major consumer of electronic products made elsewhere. This reversal has occurred even though many of the products-m both consumer and industrial electronics-were invented here, and U.S. firms still hold the patents on key innovations. The greatest setbacks-amounting to what is commonly described as the "loss" of a whole industry-have been in consumer electronics, symbolized by video recorders, which, although invented in the U.S., are not produced by any U.S. firm.

*In one branch of electronics after another, U.S. firms have failed to achieve commercial advantage from technical innovation.*

In one branch of electronics after another, U.S. firms have failed to achieve commercial advantage from technical innovation, while the Japanese and the newly industrialized countries of Asia have caught up with and in many instances surpassed their U.S. rivals in new product development. Low-cost, high-quality products from these nations have not only replaced U.S. goods in overseas markets but have displaced U.S. producers from domestic markets as well. This pattern is repeated in cases where the technology is stable-toasters, radios, and irons for example-and where the technology is changing rapidly—e.g., televisions, videocassette recorders (VCRs). semiconductors, and computers.

*The loss of consumer electronics is particularly significant as the strong competition in this industry provides a major impetus for the development of new design and manufacturing technologies.*

The loss of consumer electronics is particularly significant as the strong competition in this industry provides a major impetus for the development of new design and manufacturing technologies to support high-volume, rapidly changing designs. The same design and manufacturing techniques provide the basis for many other product lines including computers, instrumentation, and defense electronics.

### *U.S. Trade Performance and the Electronics Sector*

There are many ways to measure changes in the international competitiveness of economies and of particular industrial sectors. Among these are national and international market share, productivity growth and unit labor costs, capital investment, R&D effort, and other indicators of technology diffusion and performance. Many such measures can be applied to the worldwide competitiveness *of firms* headquartered within the nation (multinational corporations), but this is not synonymous with *national* competitiveness at the industry level or the *aggregate* economic level.

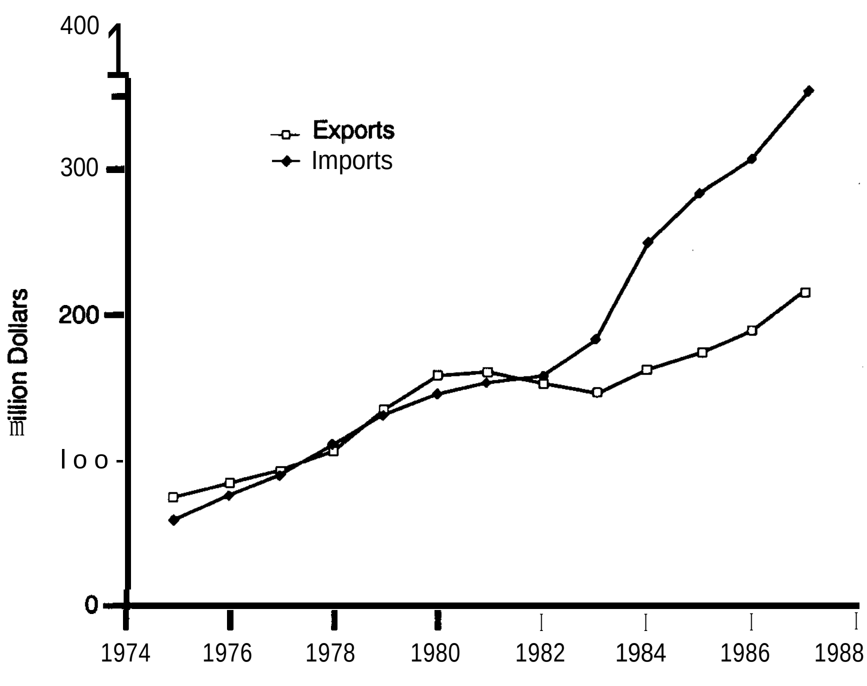
In an increasingly competitive international economy, the ***trade balance*** has become the ultimate measure of a nation's or a domestic industry's performance. Imports and exports represent twice as large a share of the U.S. gross national product (GNP) as they did two decades ago, and it is estimated that 70 percent of the goods produced in the U.S. now compete with merchandise from other countries.

***Most of the rise in the U.S. trade deficit in the 1980s has been due to the dramatic increase in imports of manufactured*** goods.

Most of the rise in the U.S. trade deficit in the 1980s has been due to the dramatic increase in imports of ***manufactured*** goods. The U.S. trade balance in manufactures fell from a surplus of $22.0 billion in 1980 to a record deficit in 1987 of $137.7 billion, with increased ***imports*** more than accounting for this net swing of $159.7 billion (see Figure 1). Rising imports of manufactured goods also account for the increase in the overall merchandise trade deficit, which by 1987 topped $170 billion, up from $3 1.3 billion in 1980. Both deficits began to come down only in 1988.

**FIGURE 1**

**U.S. Trade in Manufactured Goods**
**1975 - 1987**




Source: U.S. Department of Commerce, ***United*** States Trade ***Performance in 1987*** **(1988),** p. 100.

The general rise of the dollar of course exacerbated U.S. manufacturers' woes in the first half of the 1980s. However, against the value of the Japanese yen the dollar peaked in 1982—three years before reaching its highest value against most other currencies-and from 1985 to 1988 the dollar declined by nearly ***half*** against the Japanese currency (the effect of the recent rise in the dollar has yet to be felt in most merchandise markets). But the soaring yen, far from crippling Japanese industry in the period since 1985, propelled many Japanese firms into the higher segments of the market where they competed head on with U.S. firms in terms of quality as much as price, while imports from newly industrialized countries substituted for Japanese imports in the cheaper segments.

***The high-technology share of U.S. manufacturing imports rose by one-third from 18.4 percent to 24.6 percent between 1981 and 1984.***

All of these events have been occurring at the same time that high-technology trade is increasing relative to trade in mature sector products. The high-technology share of U.S. manufacturing imports-including most electronic goods—rose by one-third from 18.4 percent to 24.6 percent between 1981 and 1984, and was 24.7 percent in 1987. It is in these products, where U.S. firms once enjoyed exclusive control, that the competitive battles of the future will be fought, not only with Japan and other developed countries but with developing countries as well.

In 1981, a U.S. trade surplus in high-technology goods more than overcame the trade deficit in non-high-technology manufactured goods, but that high-tech surplus was transformed into a $2.6 billion deficit in 1986 (see Figure 2). High-technology exports grew from $60.4 billion in 1981 to $84.1 billion in 1987. But imports grew more, from $33.8 billion in 1981 to $83.5 billion in 1987. leaving the U.S. barely a net exporter of such goods in the latter year. The slide among non-high-technology manufactures was of course much greater, with the trade deficit increasing from $11 billion in 1981 to $138 billion in 1987.

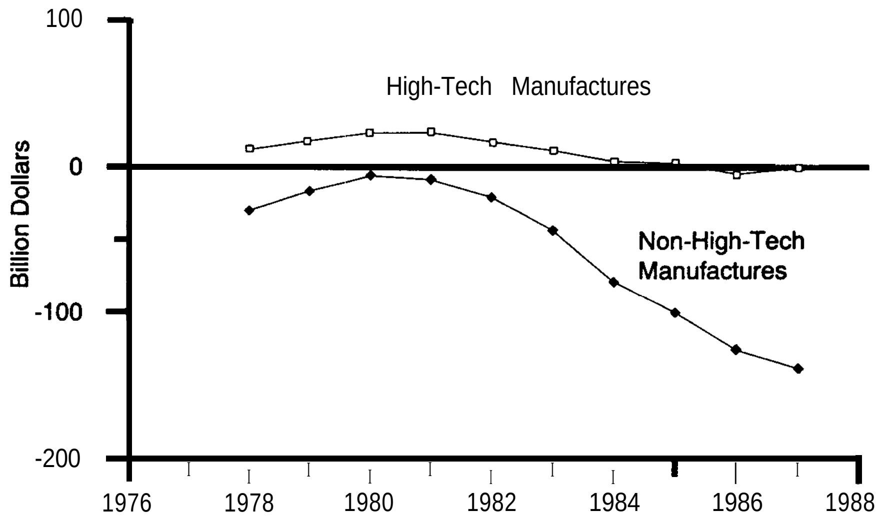
***Until the early 1980s the overall trade balance in electronics was positive and growing, despite an accelerating decline in the consumer electronics segment.***

Until the early 1980s the overall trade balance in electronics was positive and growing, despite an accelerating decline in the consumer electronics segment. By 1983. however, the total electronics balance was in deficit: and the deficit worsened by more than $4 billion per year through 1987 (Figure 3).

When we look at the pattern within the electronics sector, we see that as late as 1983 a $7.9 billion deficit in consumer electronics was nearly compensated by a $7.4 billion surplus in other electronic goods-including especially computers and industrial electronics-leaving an overall electronics deficit of just $478 million. Between 1983 and 1987 the

**FIGURE 2**

**U.S. High-Tech and Non-High-Tech Manufactures Trade Balance 1978 - 1987**




Source: U.S. Department of Commerce, *United States Trade Performance in 7987* (1988), p. 105.

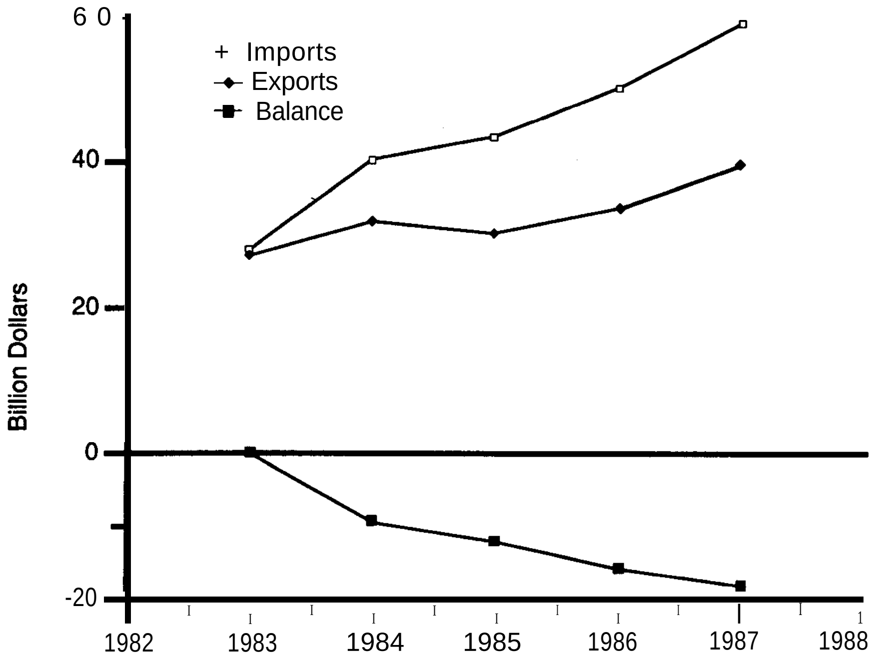
> ***What seemed to be a problem of declining U.S. competitiveness only in television receivers, VCRs, and other consumer products has emerged in the 1980s as a challenge across the spectrum of the electronics industries.***

trade problem broadened and deepened, as the continuing rise in the consumer electronics deficit accounted for just one-third ($5.7 billion) of the overall rise in the electronics deficit to $17.8 billion in the latter year. The remaining two-thirds was accounted for by the swing from a $7.4 billion surplus to a $4.2 billion deficit in non-consumer electronics.

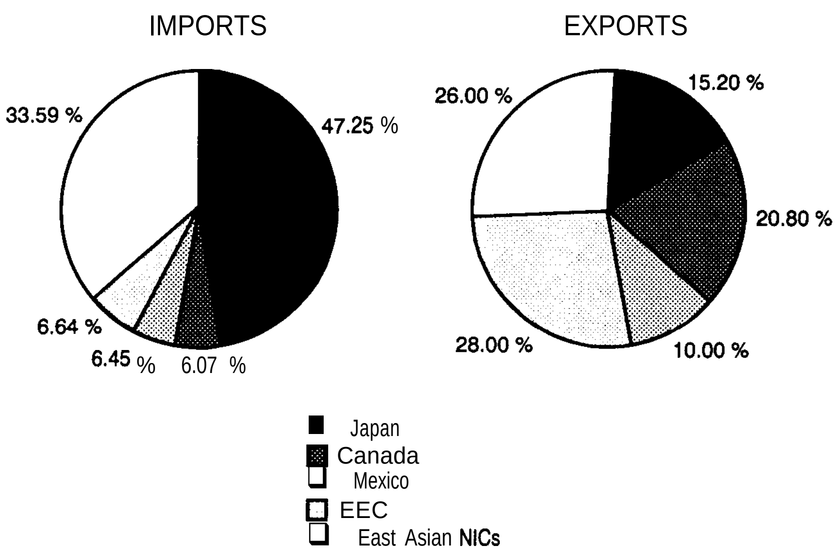
Thus, what seemed to be a problem of declining U.S. competitiveness only in television receivers, VCRs, and other consumer products has emerged in the 1980s as a challenge across the spectrum of the electronics industries. Indeed—and perhaps ironically-the U.S. balance of trade in consumer electronics actually improved marginally in 1987, due to the high value of the yen and a shift of Japanese consumer electronics assembly to facilities in the United States. But the other electronics sectors, which were led by consumer electronics into deficit, continued to perform badly.

**FIGURE 3**

**U.S. Balance of Trade:
Total Electronics Industries
1983 - 1987**




**U.S. Electonlcs Industry Trade Partners:
Shares of Trade - 1987**




Source: Electronic Industries Association, 1988.

*Even U.S. computer firms are now faced with intense competition.*

Even U.S. computer firms are now faced with intense competition. The U.S. trade surplus in electronic computing equipment 'peaked in 1981 at just under $7 billion; by 1987, it had fallen to about $2.8 billion (U.S. Department of Commerce, 1989: Chapter 26). Clones of U.S. personal computers manufactured in the Pacific Basin dominate the lower end of the market. At the higher end, where American firms once clearly surpassed everyone, foreign competitors are *also* making substantial inroads. Japanese firms produce some of the fastest machines available and have moved aggressively into supercomputer production (National Research Council, 1988:27). Japanese firms increasingly dominate worldwide production in consumer electronics and other sectors of electronics production as well.

The Japanese are now trying to secure their position in the North American market by increasing production in the United States, Canada,, and Mexico. The high value of the yen and fear of a protectionist backlash have accelerated this trend. Building on their export success, Japanese foreign direct investment and joint ventures in the United States are growing in everything from automobiles to high-technology products including computers and semiconductors. In 1985, 45 percent of the joint ventures between U.S. and Japanese firms were in these latter two industries (calculated from Japan External Trade Organization, 1985: various tables).

## *The Underlying Factors*

*How could the United States, with a clear leadership position in basic research and in the development of technologies, take a back seat when it came to market share and profits in the electronics industry?*

How could the United States, with a clear leadership position in basic research and in the development of technologies that have shaped consumer demand since World War II, take a back seat when it came to market share and profits in the electronics industry? Part of the explanation is the rapid expansion of the capabilities of Japanese firms stimulated by post-war reconstruction and based, at least initially, on technology licensed from U.S. firms.

U.S. firms willingly licensed their technology to Japanese firms that unproved on the basic designs, and commercialized these "seed technologies." Using adaptive research, development, and engineering, Japanese firms made many product and process improvements and eventually were able to capture substantial segments of export markets. The Japanese government strongly supported such development with indirect but industry-specific government involvement in the private sector (Ozawa, 1985:155).

Increasingly, U.S. firms lagged behind in developing and refining designs and production processes. Their failure to find effective organizational and strategic approaches to manufacturing and design in highly competitive sectors such as consumer electronics then led them into compensatory strategies, which also failed. These included offshore production and agreements with European, Japanese, and Southeast Asian firms to design and manufacture consumer products for sale in the U.S. under American brand names. In the end, many U.S.-based firms have removed themselves from highly competitive sectors altogether and sought refuge in the defense and service sectors of the economy. Meanwhile, building on the technologies they licensed from the U.S., Japanese firms are increasingly innovative in their own right, commercializing new technologies in the manufacture of high-quality, low-cost products.

***The Japanese government had an overall strategy to regulate technology acquisition and direct foreign investment.***

Both macro and micro factors and strategies have influenced the behavior of Japanese and U.S. firms. At the micro level, Japan's post-war policy, which favored licensing of technology while limiting direct foreign investment, has led to the development of firms with strengths in adaptive research, product and process engineering, marketing, and other techniques for commercialization of new products. The Japanese government had an overall strategy to regulate technology acquisition and direct foreign investment, using scarce foreign exchange generated by export industries (most notably textiles and clothing) to license technology for heavily protected 'infant' industries such as the chemical, nonelectrical machinery, electrical machinery, and metal industries (Ozawa, 1985: 159).

***By contrast, U.S. corporations were narrowing the focus of their strategies on individual "profit centers."***

By contrast, U.S. corporations were narrowing the focus of their strategies on individual "profit centers" (Johnson and Kaplan, 1987). The profit centers strategy requires each segment of the corporation to allocate expenses independently, making it impossible to make value-creating investments and decisions across business units. Combined with the obsession with short-term profits, this caused American managers to reduce expenditures on discretionary and intangible investments. Short-term earnings are improved by cutting expenditures on R&D. applications engineering, and other areas that are vital to a company's long-term performance (Johnson & Kaplan, 1987:201).

At the macro level, differences in the cost of capital and other macroeconomic factors have also influenced the competitive position of Japanese and U.S. firms. Landau and Hatsopoulos (1986) have shown that differences in the cost of capital between Japan and the U.S. encourage Japanese companies to invest in longer-term R&D projects and make greater investments in new process technologies and capital equipment. In addition, in the early 1980s the rising dollar clearly played a role in declining U.S. competitiveness as well, but this factor was less important vis-a-vis Japan than in U.S. trade with European nations. Nor has the generally declining U.S. dollar since 1985 done much to reduce the Japanese surplus with the U.S.

*Beginning in the late 1960s, U.S. firms sought low-cost regions outside of the United States in an effort to reduce manufacturing costs.*

This study focuses mainly on micro factors, as they affect the design and manufacture of fast turnaround products in the overall electronics industry. Factors underlying the U.S. decline in *consumer* electronics offer lessons for this broader category of products and industries. Most of the products that fit into this category-such as semiconductors, audio and video equipment, computers, and telecommunications—are still largely the province of firms with home bases in the most developed countries of the world: Japan, the United States, Western Europe, and Canada. Although the Asian newly industrialized countries (NICs) have made substantial inroads in production and sales of consumer electronics, Samsung and Goldstar-two of the most advanced firms in South Korea-are still followers in all but a few product lines.

## *Offshore Production: A Symptom Not a Cause*

Beginning in the late 1960s, U.S. firms sought low-cost regions outside of the United States in an effort to reduce manufacturing costs. In 1983, even before the value of the U.S. dollar reached its peak against foreign currencies, the United States was carrying out 17.3 percent of manufacturing in production sites outside of the U.S., whereas for Japan the comparable figure was only 3.9 percent. However, the picture is rapidly changing as the desire to mitigate trade pressure and exchange rate risk has led Japanese firms to expand production in the United States, Europe, and elsewhere in recent years.

*But offshore assembly has not been sufficient to stave off competition, and may even have fostered that competition.*

During the 1960s and 1970s, offshore assembly helped bridge the wage gap between imports and domestic production. But offshore assembly has not been sufficient to stave off competition, and may even have fostered that competition as developing countries have learned techniques and processes formerly the exclusive province of manufacturers in the United States and Europe. Taiwan, Singapore, Hong Kong, and South Korea are now able to compete independently in the production of many of the products that American firms have assembled abroad, and increasingly in the production of more sophisticated high-technology products as well.

Offshore assembly has been encouraged by Item 807.00 of the U.S. Tariff Code, which permits U.S. firms to export components for assembly offshore, paying duty only on the value added abroad when assembled products are reimported. As the capabilities of developing countries have grown, however, U.S. firms have increased the proportion of foreign-sourced to U.S. parts. This shift to parts made in developing countries has occurred at a faster rate in the newly developing countries of Southeast Asia than in the rest of the developing world. Imports from Mexico in the electrical and electronics industry, for example, still consist largely of goods assembled there from parts sourced in the United States. By contrast, imports from Taiwan, South Korea, and Singapore have fewer American parts reimported under Item 807.00 (see Table 1).

As ***the capabilities of developing countries have grown, however, U.S. firms have increased the proportion of foreign-sourced to U.S. parts.***

**TABLE** 1

Total **U.S. Imports of Selected Electrical and Electronic Products Compared with Imports under Tariff Items 806.30 and 807.00 1988**

(Customs Value Basis, in Thousands of Dollars)

| COUNTRY | 806.30 807.00 IMPORTS | TOTAL IMPORTS | PERCENTAGE |
|---|---|---|---|
| Taiwan | 702,384 | 6,140,697 | 12% |
| South Korea | 763,739 | 5,540,194 | 14 |
| Canada | 1,231,404 | 3,695,921 | 33 |
| Singapore | 1,815,378 | 5,430,006 | 33 |
| Thailand | 372,551 | 792,593 | 47 |
| Malaysia | 1,203,573 | 2,150,702 | 56 |
| Philippines | 483,928 | 691,885 | 70 |
| Mexico | 3,814,653 | 4,512,772 | 85 |
| All Countries | 11,466,453 | 68,595,450 | 17 |

Source: Electronic Industries Association, *Electronics Foreign Trade,* Dec. 1988

In the past, American firms were much more apt to use their offshore subsidiaries to supply the **U.S.** domestic market. Now that the Japanese yen has risen significantly in relationship to other major currencies, Japanese firms have begun to carry out final and intermediate assembly in the United States, Europe, and in the developing world. Japanese firms have moved **production of some lower priced products, such as radios and televisions, to their subsidiaries in Southeast Asia and Mexico, and, departing from their previous export-dominated pattern, plan to send the products back to Japan. However, design and manufacture at the high end are retained at home.**

*Offshore assembly was a reflection of the last ditch efforts of American firms to make a profit in an increasingly competitive world without making fundamental changes in design and manufacturing.*

**Extensive use of offshore assembly by U.S. firms** may **have reinforced the artificial separation between product design and manufacturing systems design, thus fostering the relative inattention to process technologies which has characterized many American firms. Offshore assembly was, however, a reflection of the last ditch efforts of American firms to make a profit** in an **increasingly competitive world** *without* **making fundamental changes in design and manufacturing. It is therefore a symptom, not the fundamental reason for the decline in the competitiveness of U.S. firms in the electronics industry.**

## *The Decline Of American Television Producers*

*One fatal mistake of most U.S. firms was to assume that television production was a so-called "mature" industry.*

The classic illustration of a "lost" U.S. consumer electronics industry is, of course, television receivers—first the black and white TV and then the production of color sets. Television is the quintessential high-volume, fast-turnaround product. The television industry illustrates the great difficulty of managing incremental change in a business in which costs decline yearly and production efficiencies must be made in order to stay competitive. Shorter-term incremental improvements and product and process technologies compete for resources with longer-term research and development for such emerging technologies as HDTV, and few firms are able to make the major investments it takes to bring such new systems to market.

One fatal mistake of most U.S. firms was to assume that television production was a so-called "mature" industry—and they carried out strategies which reflected that perception. Japanese firms, by contrast, aggressively licensed American technology and automated their production processes, moving from vacuum tube-based production to solid state electronics more rapidly than their counterparts in the United States. Reducing the **number of components by sub-**

stituting integrated circuits for vacuum tubes increased reliability and lowered labor costs.

While U.S. firms shifted their production to manual low-wage offshore plants, Japanese firms (such as Hitachi and Matsushita) developed automatic insertion machines. Automated insertion and testing helped further reduce labor costs and increase reliability. By 1968, Japanese firms had put the first generation of automated television assembly equipment in operation. As the reliability of Japanese TVs improved, Japanese firms switched to single circuit board designs, further reducing component counts.

***While U.S. firms shifted their production to manual low-wage offshore plants, Japanese firms developed automatic insertion machines.***

Ironically, quantitative limits unposed by the Orderly Marketing Agreements which the U.S. adopted in response to foreign competition in color TV had the effect of encouraging the Japanese to move their successful approach from low-value to high-value products. The movement offshore of both RCA and Zenith was accompanied by a cutback in research and development personnel and expenditures, the closing of domestic production facilities, and the transfer of existing product and process technologies abroad.

The strategic decisions made by Japanese firms were influenced by the macroeconomic conditions and other factors within their respective nations. The Japanese moved to solid state electronics partially because of their intense concern for reducing power consumption after the first oil crisis. They were aided by their government in developing precompetitive joint ventures to work on some of the basic problems in applying integrated circuits to television production. By contrast, the U.S. government had no coherent energy policy at the time and certainly no coherent policy toward the electronics industry.

***The Japanese.. . were aided by their government in developing precompetitive joint ventures to work on... applying integrated circuits to television production.***

The Japanese government played a role in advancing Japanese TV exports by setting up the Japan Machiners and Metal Institute (JMMI) in 1957. JMMI has played an important role in establishing quality standards and testing facilities. The quality standards set by JMMI were more stringent than those set by the U.S. government, and the inspection and testing time for new products entering the market ranged from 2 to 12 months and had to be carried out in Japan. The certification process inhibited the sale of U.S. televisions in Japan.

Japan's Ministry of Industry and Trade (MIT11 sponsored a multicompany project on the use of transistors in color TV circuits and in 1969, the world's first ah-transistor color TV was introduced by Hitachi. The early Japanese move to transistors was in part stimulated by the high power consumption of vacuum tube sets. Later MITI sponsored another multicompany research project to study the use of integrated circuits (ICs) in the control circuits.

## *Japanese Success in VCRs*

***Another product, the VCR, illustrates what the Japanese do right in consumer electronics.***

Another product, the VCR-developed for sale to commercial broadcasters in the U.S. in the late 1950s—illustrates what the Japanese do right in consumer electronics. Rosenbloom and Cusumano (1987) have analyzed the birth of the VCR for the mass consumer market. They compared the outcomes of the strategies, of six firms that were pioneers in the development of home video recording technology. Of the firms they analyzed, two-RCA and Ampex-were U.S. firms and four firms were Japanese. The Japanese firms studied were Victor Company of Japan (JVC), Matsushita, Sony, and Toshiba.

In the late 1970s and early 1980s, Matsushita, JVC, and Sony were the leading producers of VCRs for home use, sharing 80 percent of the 1978 output and retaining 57 percent of the 1984 market. Rosenbloom and Cusumano concluded that the different outcomes for the successful Japanese and unsuccessful American firms were due to differences in the management of technology rather than "first mover advantages" from true technical innovation (1987:51).

***The path to competitive advantage lay in incremental improvements and then the integration of design and manufacturing.***

The VCR is a "systems" product which depends on the successful integration and performance of diverse technologies, and the development of production techniques to reduce costs sufficiently to appeal to a mass consumer market. Rosenbloom and Cusumano point out that cost reduction depended on developing new techniques for high-volume and high-precision assembly of mechanisms, the mass production of circuit boards, and the precision fabrication of components of the magnetic and mechanical subsystems. In Rosenbloom and Cusumano's words: "The path to competitive advantage lay in incremental improvements and then the integration of design and manufacturing" (1987:5 1).

An essential element in following that path was long-term commitment to a strategy for producing a low-cost product, that could be sold to consumers for home use. Equally important was the extremely capable technical leadership that operated at or close to the top of the management in the three successful Japanese companies. Additionally. the team approach to design and manufacturing and the tremendous engineering resources allocated to projects-from initial conceptualization of the design through the production and selection of product prototypes, the manufacturing systems design, and, finally, production-were factors critical to their success.

During the critical design and testing phases, Sony's design team systematically tried different ways of building a home VCR. After 18 months, the best prototype was selected and the design team spent another 18 months working with production engineers to prepare it for manufacturing. Most of the original group followed the project into the production engineering department to ensure a smooth transition to mass production. Likewise, at JVC, Rosenbloom and Cusumano report a close communication between design engineers and manufacturing operations. Work continued on both design and production in parallel at a single site.

**Few American firms are *willing to commit the level of* engineering resources *required by the* Japanese *approach to design-for-manufacturability.***

Gomery and Schmidt (1988) contrast the design cycles in Japan with those in the U.S. in a recent paper. In the design cycle, U.S. firms have traditionally focused on the features and performance of a new product rather than on the process by which it will be manufactured. Japanese designers, by contrast, are oriented to simplicity in their designs. Japanese firms make low-cost manufacturing an explicit objective of design. Japanese designers are given a cost target which they must meet, and they try to optimize changes to permit further cost reductions in successive generations of products. Few American firms are willing to commit the level of engineering resources required by the Japanese approach to design-for-manufacturability.

## The Hollowing of the American Corporation

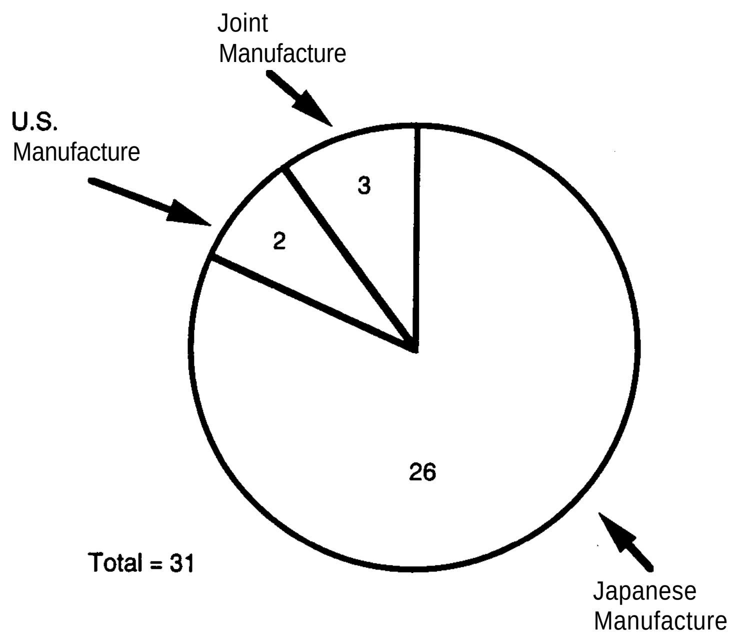
**The withdrawal of *many U.S. companies from producing highly competitive consumer and industrial electronics products led to an increase in arrangements whereby Americanfirms have other firms produce products for them.***

The withdrawal of many U.S. companies from producing highly competitive consumer and industrial electronics products led to an increase in arrangements whereby American firms have other firms produce products for them. The majority of such arrangements (called original equipment manufacturer, or OEM agreements) between U.S. and foreign firms rely on the foreign firm to do both the manufacturing and the design for the U.S. firm. Until RCA sold its consumer electronics division, VCRs, for example, were produced by Hitachi under the RCA label. A wide variety of other products are now produced by foreign firms and sold under American brand names: NEC produces large capacity computers for Honeywell; Mitsubishi Electric makes automobile telephones for ATT Technology; Canon makes laser printers for Hewlett-Packard; Toshiba makes compact disc players for General Electric (GE); Ricoh makes laser printers for Digital Equipment: Toshiba makes electric ranges for Amana; and the list goes on. Increasingly, companies in the newly industrialized countries of Southeast Asia (such as South Korea's Goldstar and Samsung) are important sources of manufactured goods sold under American labels. OEM agreements generally go in one direction, with Japanese firms almost always providing manufacturing for the American firm (see Figure 4).

*Although several **American firms** were contenders in the battle for the development of the VCR, no **American firm** today produces VCRs.*

**FIGURE** 4

**OEM Agreements In Electrical And Electronics Industries * Between U.S. and Japan (1985)**




* Includes high-tech components, semiconductors, integrated circuits, and computer-related products

Source: Calculated from agreements listed in Japan External Trade Organization "Cooperation Between American & Japanese Firms, Cases of Industrial Cooperation in 1985."

Thus, by choosing such an arrangement, the U.S. firm will often give up any possibility of playing a serious role in the development and manufacture of the next generation of the product, or of new products created as a result of the experience base developed. Although several American firms were contenders in the battle for the development of the VCR, no American firm today produces either VCRs or their direct descendants, digital audio tape (DAT) recorders.

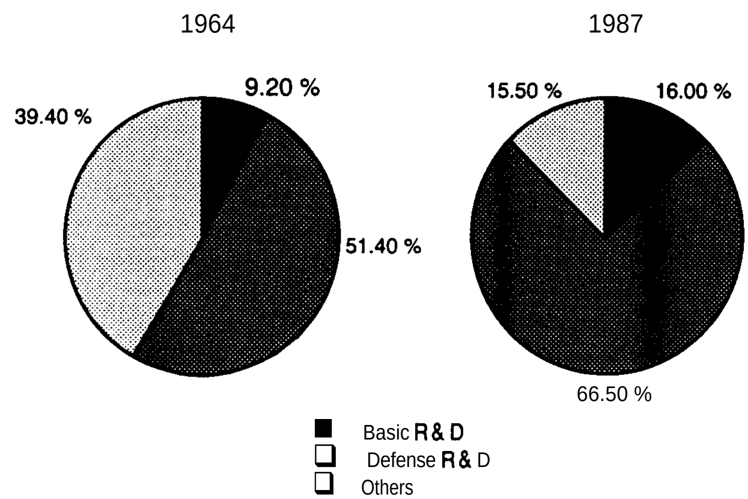
## *Defense Spending: A Niche of Last Resort*

A final factor underlying differences between Japanese and U.S. capabilities for producing fast-turnaround electronics products is the heavy reliance of many U.S. firms on defense spending. The U.S. spends $1,200 per capita on defense, two times the rate of Great Britain, three times the rate of Canada, and six times the rate for Japan (Adams. 1985:25). The Department of Defense is directly responsible for the bulk of research and development expenditures and is the most influential and powerful force in determining how federal funds will be allocated. The proportion of defense related research and development expenditures of the total R&D budget rose from 5 1.4 percent in 1964 to 68.4 percent in 1987 (see Figure 5).

***Traditional defense procurement tends to emphasize the production elements that are not highly rewarded in the commercial marketplace.***

**FIGURE 5**

**U.S. Government-Funded Research and Development by Type of Research 1964 & 1987**




Source: John Adams, "The Price of Might," IEEE Spectrum, Nov. 1985, p. 26.

Traditional defense procurement tends to emphasize the production elements that are not highly rewarded in the commercial marketplace. Production tends to be low-volume and often on a cost plus basis. Much attention is given to redundancy in defense systems, and products are generally overdesigned from the commercial standpoint-highly reliable but also more costly to produce, even on a small scale. In mass consumer products, sleek and simple designs with high reliability are desired, and the actual cost of the product must be low enough to be affordable by large numbers of households. Overdesign often leads to higher production costs and can be a disaster in the commercial marketplace.

*Many U.S. design engineers are weaned on defense products and tend to think in terms of producing the most state-of-the-art product with little attention or concern to what it will cost to produce it.*

Many U.S. design engineers are weaned on defense products and tend to think in terms of producing the most state-of-the-art product with little attention or concern to what it will cost to produce it. This is reinforced in graduate school where Ph.D students may be supported by defense contracts or carry out research under government contracts with little emphasis on production for the mass market.

*Japanese firms typically work from completely different assumptions and take manufacturability-the cost and reliability of production—very seriously.*

Japanese firms typically work from completely different assumptions and take manufacturability-the cost and reliability of production-very seriously. They devote a large proportion of their engineers (often the best and the brightest) to developing manufacturing technologies. Organizationally, they tend to be more "factory focused" than are U.S. firms. They stress constant contact between product design engineers and manufacturing systems engineers from the inception of the product idea through full implementation of the new product on the production line.

The shift of America's major firms away from producing products such as video recorders and memory chips is frequently viewed as an inevitable and sensible progression away from production where the turnover is quick, volume is high, and the profit margins are razor thin. But such a move seriously impairs their abilities to produce the next generation of products as well as to develop underlying patterns of organization and management of technology conducive to high-volume, fast-turnaround products.

Only the firms which took a leadership role in developing the VCR have been able to develop compact disc recorders, which are based on digital optical storage, and finally DAT recorders, which combine VCR recording with digital encoding. Japanese firms have realized tremendous profits from selling VCRs and compact disc recorders in the United States, and are likely to do even better when DAT recorders finally come on the market. Just as no American firm produces VCRs or compact disc recorders, none are likely to produce DAT recorders in the future.

Equally serious is the movement of some major U.S. firms out of competitive markets altogether. Fifteen years ago GE and RCA were the nation's foremost producers of consumer electronics products. Both firms have opted out of the consumer electronics industry and no longer produce commodity chips. They have refocused their efforts on defense, high-technology products, and financial services. With

GE and RCA out of important segments of the electronics business, the United States has lost two of its strongest competitors. With the possible exception of Zenith, there is not currently, nor if present trends continue is there likely to be in the near future, a single American firm producing high definition television and other advanced consumer electronics products.

***With GE and RCA out of important segments of the electronics business, the United States has lost two of its strongest competitors.***

## Opportunities and Challenges for U.S. Reentry Into Consumer Electronics

Although the United States has lost much ground in electronics and other key industries, advances in product and process technologies, compressed product and process cycles, and the increased use of semiconductor technology to replace functions previously carried out by electrical and mechanical devices present both an opportunity and a challenge for American firms to get back into consumer and industrial products in a serious way. In this chapter we examine the nature of those changes and the impact they are likely to have on the competitive position of American firms in the electronics industry.

During the past year, many have come to view the development of high definition television-a new breakthrough technology with wide applications in electronics-as an opportunity for U.S. firms to get back into the consumer electronics industry. The American Electronics Association (AEA) and the Defense Advanced Research Projects Agency (DARPA) are promoting R&D partnerships for the development of HDTV. Interest in the DARPA funded effort has been intense. Already some 80 proposals have been submitted. Despite the intense interest, the role U.S. firms might play as principal developers and suppliers of HDTV to the consumer marketplace is still uncertain. Except for Zenith, all other original equipment picture-tube manufacturers in the U.S. are foreign owned.

HDTV has become the bellwether for U.S. readiness to meet the challenge of a new generation of integrated information technologies. Successful commercial ventures in this arena will combine access to large viewer audiences with the technology to manufacture complex electronics systems at a cost that matches consumer demand. Predictions from Japanese and American analysts suggest that HDTV will be sold to 10 percent of U.S. households owning sets by 1997 and 20 percent by the year 2000. It is estimated that sales in the U.S. will reach $23 billion by 2003 and employ more than 200,000 workers in manufacturing (Nathan, 1988).

*Many have come to view the development of high definition television as an opportunity for U.S. firms to get buck into the consumer electronics industry.*

***HDTV....will combine access to large viewer audiences with the technology to manufacture complex electronics systems at a cost that matches consumer demand.***

### *The Importance of High Definition Television*

High definition television is the next generation of television technology now under development by broadcasters, Direct Broadcast from Satellite (DBS), cable and fiber optic interests, and TV manufacturers. HDTV promises to bring sharper pictures to the TV screen as well as superior digital stereo sound and wide screen pictures. The current National Television Standards Committee (NTSC) standard, which has 525 scanning lines and an average resolution of 350-by-350 lines per picture height, is 40 years old. HDTV will scan more lines and provide greatly improved clarity and sharpness. The transition from television, based on the older NTSC standard, to HDTV will not occur overnight, but it will come; HDTV is a major new technology, affecting not only the firms currently competing in the television industry, but other industries such as telecommunications, computers, and defense electronics.

***The transition from television, based on the older NTSC standard, to HDTV will not occur overnight, but it will come.***

Although their direct impact is substantial, the indirect impacts of these technologies are even more important, some analysts maintain. According to the president of the Institute of Electrical and Electronics Engineers' (IEEE) Robotics and Automation Society, Arthur C. Sanderson, it is the indirect impacts which are of major concern for the U.S. electronics industry.

> HDTV will become an *embedded computer* product, that is computing hardware and software will be integrated into the HDTV system. The transmission and storage, processing and reception of HDTV signals will increasingly be carried out using digital computer architectures. The continued evolution of functionality of the product will depend on the development of effective embedded architectures which perform complex operations at very high speed. In this sense, one may view HDTV as a technological forcing function which drives the development and manufacture of efficient computing technologies in a real-time, cost-competitive environment. The challenge to the dominance of U.S. computer manufacturers, as well as U.S. defense electronics manufacturers, is becoming increasingly clear. HDTV could be the flrst step toward a much wider competition in high technology products (A.C. Sanderson, 1989).

***HDTV could be the first step toward a much wider competition in high technology products.***

As our earlier discussion makes clear, the transition from vacuum tubes to solid state electronics was a similar watershed in the television industry, which led to the rise of Japanese firms and the decline and exit of most U.S. firms from the industry.

## *Market Challenges and the Compressed Product Cycle*

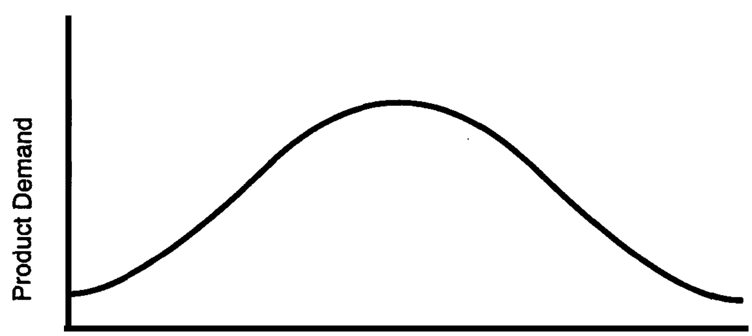
In the new international environment in which U.S. firms are competing, market demands as well as the nature of competition are changing and increasing. Cost and quality were the chief bases for competition during the 1960s and 1970s. During the 1980s, variety or assortment of products, speed to market, and quality have come to be the major sources of competitive advantage. Firms that hope to compete in an increasingly global and competitive environment will have to bring a wider variety of high-quality, low-cost products to an increasingly sophisticated and discriminating global market. Time is a competitive weapon in the global marketplace.

***Time is a competitive weapon in the global marketplace.***

Most business school graduates have been taught that as a product grows in volume it becomes standardized and may be produced economically by investing in fixed processes. Traditionally the product cycle has followed the development, production, and marketing of single products whose demand gradually increases, saturates, and eventually declines. Such a cycle is illustrated in Figure 6.

**FIGURE 6**

**Schematic Diagram Of Product Cycle**




***As a product matures and its technology becomes stable, the comparative advantage in production moves to regions where wages and operating expenses are lower. But the Japanese have turned this proposition on its head by demonstrating that high-quality, low-cost goods can be produced where wages are relatively high.***

Since Raymond Vernon of the Harvard Business School introduced the concept of the product cycle in the late 1960s, it has also been the accepted wisdom that as a product matures and its technology becomes stable, the comparative advantage in production moves to regions where wages and operating expenses are lower. But as our earlier discussion illustrates, the Japanese have turned this proposition on its head by demonstrating that high-quality, low-cost goods can be produced where wages are relatively high. They have demonstrated this for "mature" products as well as new ones. A new product may be functionally similar to its post-war ancestor (for example, the television set or the automobile), but new designs, materials, and production processes may make it radically different from its predecessor. This can help determine who the state-of-the-art producer will be, and where production will be located.

In the global marketplace today-especially in electronics-the time between the introduction and the maturity of products and processes has decreased from 3 to 4 years to something on the order of 18 to 24 months. The compressed product and process cycles have important implications for firms as well as for countries in an increasingly competitive global market, and these implications are quite different from those based on earlier models of the product cycle.

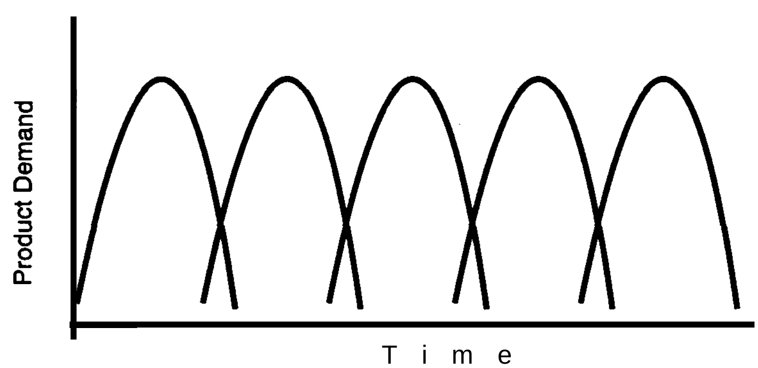
**The *time between the introduction and the maturity of products and processes has decreased from 3 to 4 years to something on the order of 18 to 24 months.***

Rapid changes in product design and in manufacturing methods require constant interaction between design, engineering, and production staffs. Time delays are less acceptable for products which are undergoing rapid evolution than for mature. products in which technological changes have slowed or stopped altogether.

Individual firms have great difficulty in the development, production, and marketing of such short-life products with rapid design changes. This situation is illustrated in Figure 7 by steep cycles with shorter duration. Within a given time frame, firms must be prepared to cope with a succession of new products, each rapidly maturing yet linked by common manufacturing processes and market demands to the other.

**FIGURE 7**

**Product Cycle with Rapid Changeover**



***Companies who hope to compete in global markets will need to develop the capability to bring new products to the market quickly.***

Rapid technological change has thus sped up the cycle of product development, making it difficult for firms to reap the benefits of production before the product becomes obsolete. The difficulty of making a profit in such a rapidly changing environment is illustrated by the compact disc player which has only recently begun to generate profits for the firms who manufacture and sell the systems. Compact disc players are already challenged by digital tape recorder technology, which makes it possible to record and hear sounds of exceptional quality. The Japanese (Sony and Matsushita) and European (Philips) firms who developed both technologies have agreed to delay the introduction of DAT recorders so that they might recoup some of the investment costs from the continued sale of compact disc players.

This pattern is repeated in virtually all segments of the electronics industry today. According to Ian Ross, President of AT&T Bell Labs: "For most of this century, advancements made telephone equipment obsolete every 15 years or so. Now it is happening every year." Companies who hope to compete in global markets will need to develop the capability to bring new products to the market quickly.

## *Engineering Challenge: Integrated Design and Manufacturing*

***If the U.S. is to reenter consumer electronics, U.S. firms must also master new models of 'simultaneous engineering" pioneered by the Japanese.***

Accelerated product cycles pose new challenges to the classical U.S. manufacturing model, in which product development proceeded step-by-step through market analysis, product design, manufacturing, and sales. This old, sequential approach to developing new products is no longer adequate in today's fast-paced, fiercely competitive world. Thus if the U.S. is to reenter consumer electronics-or remain in the broader electronics race-U.S. firms must also master new models of "simultaneous engineering" pioneered by the Japanese.

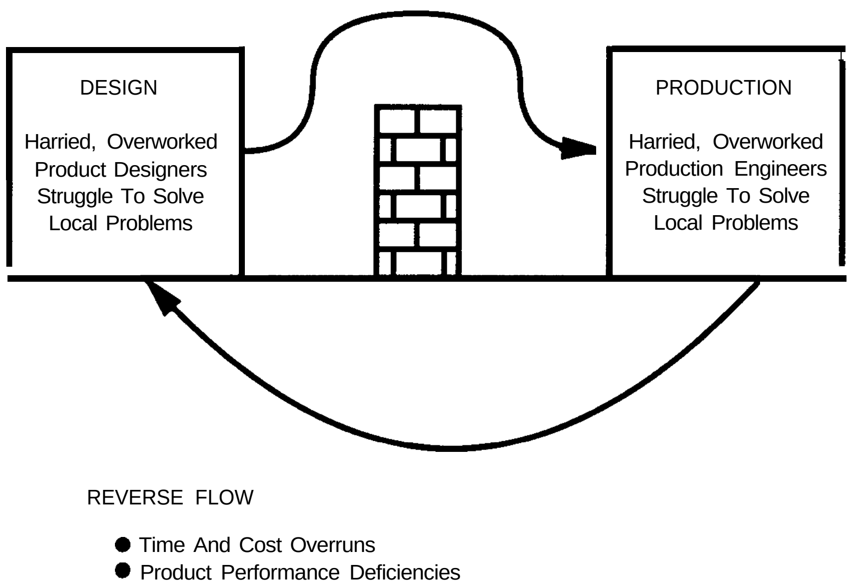
As Hirotaka Takeuchi and Ikujiro Nonaka reported recently in the *Harvard Business Review:*

> The rules of the game in new product development are changing. Many companies have discovered that it takes more than the accepted basics of high quality, low cost, and differentiation to excel in today's competitive market. It also takes speed and flexibility (1986: 137).

Figure 8 illustrates the consequences of the classical sequential model of new product development. The phased product development and design approach resulted in costly engineering changes made late in the project. Time and cost overruns and product performance deficiencies often resulted.

**FIGURE 8**

**Consequences of the Phased Product Development and Design Approach**




***In* passenger vehicle *development projects of 20 auto companies... Japanese projects are about 30 percent faster and use about one-third of the engineering hours used by their U.S. and European counterparts.***

In a recent study of product development in the automobile industry, Clark, Chew, and Fujimoto (no date) found that in passenger vehicle development projects of 20 auto companies in Japan, Europe, and the U.S., Japanese projects are about 30 percent faster and use about one-third of the engineering hours used by their U.S. and European counterparts. While differences in project scope and complexity explain some of the Japanese advantage, much of it comes from differences in organizational structure, in the degree of engineering specialization and the process of problem solving-Le., from "a different engineering paradigm." The authors point out that this "different engineering paradigm" is not uniquely Japanese, since those European and U.S. projects that employ elements of it have achieved some significant results.

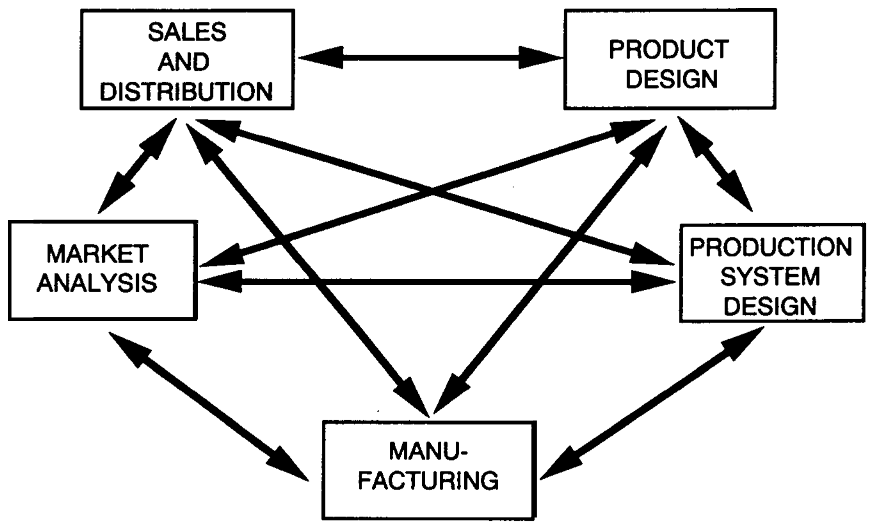
***The essence of the simultaneous engineering approach is to "get it right the first time," by tailoring &sign and manufacture to end uses.***

The essence of the simultaneous engineering approach is to "get it right the first time," by tailoring design and manufacture to end uses (see Figure 9). Simultaneous engineering is being adopted internally by firms in order to streamline new product development and achieve greater matching of new products and processes. These same techniques are being used in supplier relationships-with early involvement of key suppliers in the design of the new products. The Japanese, with their special long-term relationships with suppliers, reduce lead times using these suppliers to provide detailed designs of components and parts faster and more effectively than can be done in-house.

***New computer-imaging techniques, including virtual product design, permit flexible production of multiple products or multiple models on the same production facility with low cost and rapid changeover between production cycles.***

**FIGURE 9**

**Simultaneous Engineering Model**




Source: Industrial Technology Institute.

***Many of the tools and techniques for carrying out simultaneous engineering and virtual product design are still in the early stages of development.***

As product and process cycles shorten, new computer-imaging techniques, including virtual product design (SW. Sanderson, 1989), permit flexible production of multiple products or multiple models on the same production facility with low cost and rapid changeover between production cycles. The techniques to accomplish this require the development of organizational and control principles as well as the introduction of more programmable equipment and devices.

Many of the tools and techniques for carrying out simultaneous engineering and virtual product design are still in the early stages of development and will need long-term support. New design tools are being developed that help integrate computer modeling of products and processes.

Researchers are working on the development of database tools, product design environments, systems design environments, and graphical interfaces. Computer networks, common databases, and distributed control and software are providing the tools to integrate and coordinate manufacturing processes. These tools will provide the technical basis to make virtual design and simultaneous engineering for manufacturing feasible.

*Simultaneous engineering requires the effective interaction of people from different disciplines and across different functional groups.*

There are several obstacles slowing the adoption of this new approach to product and process design in American firms. Simultaneous engineering requires the effective interaction of people from different disciplines and across different functional groups. The functional pattern of organization which has characterized many American firms, as well as the careful delineation of tasks on the shop floor, have impeded such interdisciplinary efforts. This has been the case in the firms themselves as well as in universities where much of the basic research and training of the workforce takes place.

Because the cost of designing manufacturing systems is enormous, techniques are being developed to effectively measure, simulate and predict performance, reliability, and quality of output. Planning tools which systematically incorporate both technical and economic factors in order to predict outcomes and guide decisionmakmg are increasingly important for the successful management of these new manufacturing systems. New planning systems and management tools also provide the basis to evaluate and improve economic and organizational constraints on the performance of manufacturing systems.

*Another important challenge for American firms is to find ways to use microelectronics to their full advantage.*

## *Building the Silicon Culture: The New Competitive Challenge*

Another important challenge for American firms is to find ways to use microelectronics to their full advantage. The commercial viability of product lines ranging from consumer electronics to mainframe computers hinges on the ability to develop chips which will become part of systems, and increasingly, to prototype those systems directly in silicon.

Improvements in very large scale integration (VLSI) architectures, applications specific integrated circuits (ASICs), and in the processes that translate these designs into silicon chips make it increasingly possible to produce products at low cost and high capability. But there have been obstacles to the widespread use of VLSI designs. Turnaround times from design to silicon prototype range from a few weeks to several months, and there is no assurance that the chip will function as planned. This lengthy turnaround time and uncertain outcome have stalled the use of VLSIs in many products. ASICs may help provide a solution to this problem by shortening the turnaround time from design to availability, using standardized modular design methods and standardized manufacturing processes.

*A short turnaround time for prototyping the chips, in which the engineer can literally "try it in silicon," will be a prerequisite for commercial success.*

A short turnaround time for prototyping the chips, in which the engineer can literally "try it in silicon," will be a prerequisite for commercial success. Building a silicon culture is the next challenge facing American business, and the success of electrical and electronics firms in the 1990s will depend upon building that culture today.

Building such a silicon culture depends as much on organization as it does on technological innovations. While U.S. firms possess much of the technology to put such a system in place, many lack the organizational and managerial will to implement it. Japanese firms, by contrast, already have many of the organizational prerequisites for developing a silicon culture.

The new silicon culture rests on three technological and organizational prerequisites:

1. The infusion of computer-aided design (CAD) capabilities into many different parts of the organization.

2. The standardization and integration of computer-aided design tools.

3. The ability to transfer and to verify designs, and to fabricate, package, and test chips for many different kinds of applications and systems.

*What is missing is the ability to prototype systems components directly in silicon, bypassing the lengthy and costly cycle of creating products out of circuit boards and, some years later, putting the function on a single chip.*

Large U.S. firms typically have two kinds of semiconductor production facilities. The first is the commercial division which makes chips for internal use as well as external customers on a profit and loss basis. These facilities are geared to large batches and the economies of commercial production. They also have "clean rooms" located in research and development centers. These facilities concentrate specifically on designing and testing semiconductor devices with the goal of developing new chips which can become commercial products. What is missing is the ability to prototype systems components directly in silicon, bypassing the lengthy and costly cycle of creating products out of circuit boards and, some years later, putting the function on a single chip.

The person who designs the algorithm-the computational procedure encoded on the chip-should have the ability to put the design directly on a chip, test that chip, and modify the design. This requires a separate facility for quick turnaround of very small batches of chips as well as skilled programmers who could, at a minimum, run a CAD station and, with the aid of expert systems design tools, design chips for systems applications.

American firms face two obstacles in developing this silicon culture. First is the lack of engineering skills appropriate to implementing and utilizing the new design and manufacturing techniques. Most firms already have large numbers of technicians and engineers on their payrolls, but few of these have experience in designing chips.

A second major obstacle is the expense of operating such a semiconductor facility, which will require massive new investment in state-of-the-art equipment. Such facilities cannot be justified on commercial grounds, for the number of individual chips produced would of necessity be very small. Rather, they must be undertaken for the contribution they make to the production of a wide variety of products within the firm. This goes against the gram of the short-term profit center orientation of American business.

***Massive new investment in state-of-the-art equipment....must be undertaken for the contribution they make to the production of a wide variety of products within the firm.***

## *Investments in the Future: The Missing Middle*

The greatest challenge for firms operating in today's highly competitive environment is to balance current production goals and improvements against future technological development. Firms frequently fail to devote sufficient resources to R&D in so-called mature industries, such as the television industry, as they get into the mindset that mature markets will not bear the costs of major new innovation.

***Firms frequently fail to devote sufficient resources to R&D in so-called mature industries.***

For more than a decade, most of the changes in television production have been incremental, with improvements in production technologies, quality, and cost playing a key role in the competition. Producers of color televisions must be able to respond to rapidly changing market demand, annual decreases in selling prices of about five percent, and the necessity for high technical diversity in order to achieve the necessary market diversity. Model lifetimes are short, generally one year to two years, and production is characterized by short runs with frequent changeover.

This is an extremely difficult manufacturing environment-common to all high-volume, rapid-turnover products—and presents major challenges for firms to operate profitably. Firms must constantly upgrade their production methods, look for ways to cut costs and streamline production, while at the same time maintain quality and innovative technological improvements. If U.S. firms are to reenter consumer electronics, via HDTV or otherwise, they face peculiar challenges to making "investments in the future."

***If* U.S. *firms* are to reenter consumer electronics... they face peculiar challenges to making "investments in the future."**

Mitchell and Hamilton ( 1988) have pointed to a problem that arises from U.S. firms' reliance on traditional approaches to funding R&D within corporations. They note that management funding decisions for R&D are generally guided by two viewpoints: (1) R&D as a necessary cost of business and (2) R&D as an investment. Treating R&D as an overhead expense is most appropriate for early-stage or exploratory research efforts. Treating R&D as business investment with the allocation of investment funds according to consistent and explicit financial criteria is most appropriate for those technical, development, and engineering programs that are well understood and where the market for the output is well known.

A problem arises, say Mitchell and Hamilton, for an important segment of technical activity which lies between basic R&D and full-scale production. This segment covers applied research, exploratory development, and sometimes feasibility demonstration. According to Mitchell and Hamilton,

***A problem arises...for an important segment of technical activity which lies between basic R&D and full-scale production.***

> It is here where most difficulty is experienced with the two prevailing funding models. On the one hand, the expenditures are often too large for management to feel comfortable treating them as an overhead or cost of doing business. On the other hand, the potential impact of the program is often still sufficiently uncertain as to preclude meaningful ROI (return on investments) measures ( 1988: 16).

In making its $60 million request to the U.S. government for support for the development of a high definition television tube based on its flat tension mask tube technology, Zenith's Chairman and CEO, Jerry Perlman, expressed the sentiment of many U.S. firms when it comes to committing corporate resources to the development of risky new technologies. The domestic TV industry, according to Perlman, can no longer afford the investment to develop HDTV.

> We'd have to drag it out over a long period of years because there isn't any way we're going to put $15 million of our money, given the current profitability in the consumer business, into a one-year development program to prove out the technical feasibility. [If the government doesn't come through,] we'll sell it to

someone else a la a venture capital partnership (*TV* Digest, October, 1988: 11).

The reluctance of U.S.-based firms to make significant investments in risky new technologies is a central problem. U.S. firms frequently await the development of a market before they make large investments in new technologies, assuming that they can "leap frog" the competition and move directly into mass production. The careful, incremental approach to new product development and commercialization practiced by the best Japanese firms has proved more successful than U.S. firms' efforts to bypass essential development stages. Japanese firms are estimated to have spent over $700 million over the past 20 years on advance definition television and will undoubtedly spend millions more before the first high definition television set comes off Japanese assembly lines in 1990.

***U.S. firms frequently await the development of a market before they make large investments in new technologies, assuming that they can "leap frog" the competition and move directly into mass production.***

Although the outcome of the struggle for dominance in the next generation of television production is far from determined, it would appear that those companies that have already made a serious commitment of resources to the development and commercialization of HDTV would have a major advantage over those that have not. If we look at these investments from the perspective of Mitchell and Hamilton (1988), these firms have created a strategic option for themselves which may have far-reaching consequences for the future in the television and related industries.

## *Chronic Entrepreneurialism: A Symptom Not a Cause*

***Fragmentation, instability, and "chronically entrepreneurial" high-technology firms that are unable to sustain large, long-term investments have been blamed for the competitive problems in some U.S. industries.***

Fragmentation, instability, and "chronically entrepreneurial" high-technology firms that are unable to sustain large, long-term investments have been blamed for the competitive problems in some U.S. industries. Some scholars believe that American industries, such as aircraft and chemicals, and now semiconductors, owe their vitality to the strength and foresight of a few large companies. The core of this argument rests on the notion that only the largest firms, with sufficient capital resources, will be able to make a significant contribution to the future development of the semiconductor industry and downstream industries such as computers and electronics (see Ferguson, 1988).

This viewpoint misses the central role in the success of large Japanese manufacturing firms of intense internal competition and close relations with small firms. In the Japanese automobile industry, for example, Clark (19881 has demonstrated that intensive supplier involvement in engineering accounts for a significant fraction of the Japanese automakers' advantage in lead time and cost.

*Effective transfer of technology and support for firms creating new components using new technological capabilities are pressing national needs.*

Systems assemblers no longer have the ability to encompass all of the main techniques and technologies that are used in their final products. Advances in materials technologies and in other key areas are simply moving too fast for the final assembler to have all the knowledge required to design and produce products most effectively. When an engineer in a systems firm sets the specifications for a part, he typically does not know whether slight modifications in the shape of the design would allow for superior performance or lower production costs.

Moreover, many smaller suppliers lack the capital to finance the elaborate test facilities or experimentation programs that would allow them to improve their basic designs and meet increased demands for high quality and reliability. Effective transfer of technology and support for firms creating new components using new technological capabilities are pressing national needs.

To date, the U.S. has done little to improve the manufacturing capabilities of small suppliers. Although systems producers have attempted to assure high quality and reliability of the parts that smaller suppliers deliver to their factory floors through the use of vendor qualification programs, the sharing of engineering expertise-so widespread in Japanese industry-is largely absent in the U.S. The system of defense contracting that insists on arm's length relationships between prime contractors and subcontractors. may be one of the key reasons for the high cost and slow production of defense material.

*Young entrepreneurial firms frequently come up with innovative new products but are unable to commercialize these products because they lack sufficient resources.*

Young entrepreneurial firms frequently come up with innovative new products but are unable to commercialize these products because they lack sufficient resources to support the substantial development costs that are a prerequisite for high-volume sales. This problem was illustrated by a recent dispute between Fusion Systems Corporation, a small American firm based in Rockville, Maryland, and Mitsubishi, the giant Japanese producer. Fusion Systems Corporation charged that the Mitsubishi Electric Corporation has infringed on its patents by applying for hundreds of "knockoff" patents (Yoder, 19881.

The patent dispute stems in part from differences in how each nations' firms innovate. Much of America's technological strength is in small companies like Fusion who develop key new technologies but generally do not have the resources to follow through. Japanese industry is dominated by such giants as Mitsubishi with $18.9 billion in worldwide sales compared to Fusion's $25 million.

Mature firms and smaller entrepreneurial firms in the U.S. have major roles to play in the future development and commercialization of new technologies and products. One of the biggest challenges that large and small U.S. firms face is how to get the most out of what each has to offer. This is as true for the component and subassembly supply networks of larger systems firms as it is for the software and semiconductor firms that provide designs on discs and chips. The key for the U.S. is to find new and more effective ways to mobilize the talents of both small and large firms.

***The key for the U.S. is to find new and more effective ways to mobilize the talents of both small and large firms.***

## *The Strategic Challenge in HDTV*

Japanese and European firms have made a long-term commitment to-the development of HDTV. Many firms made the strategic decision to invest substantial sums of money into the development and commercialization of HDTV despite the intense competition and the necessity to reduce costs in current operations. This fact more than any other explains their success to date. In addition to the commitment the firms have made, they have been able to work closely with their government to ease the way for the acceptance of new technologies through the early setting of technical standards and cooperative precompetitive ventures which helped to develop the basic feasibility of the new technology.

In 1970, the Nippon Hoso Kyokai (NHK)—Japan's state-owned television company-set up a consortium of Japanese companies including Sony Corporation, NEC, and other major electronics producers to develop hardware for HDTV. Ten years later-after spending $500 million-the Japanese firms had developed working HDTV cameras and video tape recorders. Currently, the Japanese Ministry of International Trade and Industry is working with 12 manufacturers to develop jointly large color liquid crystal displays (LCD) to be used for consumer products such as the ultra-thin wall-mounted direct-view color TV and ultra-thin copiers. The Japanese group, which included Casio, Hitachi, NEC, Sanyo, Seiko, Epson, Sharp and six other business equipment operating and chemical firms, plans to spend $74 million over the next seven years-the firms providing 22 million and the Technology, Research and Promotion Center the remaining $52 million (*TV* Digest, September, 1988: 13).

***In 1970, NHK—Japan's state-owned television company-set up a consortium of Japanese companies including Sony Corporation, NEC, and other major electronics producers to develop hardware for HDTV.***

The NHK played a role in helping to allocate private Japanese development efforts, in order to prevent duplication of effort. However, the commercial implementation and major investments were left to individual companies. Of the estimated $700 million spent by the Japanese in the development of HDTV by 1966, less than 15 percent was provided by the government owned NHK (Japan Finance Institute, 1989).

***The NHK played a role in helping to allocate private Japanese development efforts, in order to prevent duplication of effort.***

At the same time, NHK proposed a new standard for TV. HDTV broadcasting requires an amount of signal information five times greater than that used under the NTSC broadcast standard. This means that in order to accommodate existing channels, a larger proportion of the frequency spectrum must be allocated to television signals.

Television broadcasters share the electromagnetic frequency with radio and telephone users. Various parts of the radio spectrum are allocated to different uses (e.g., television emergency radio communications, military communications, and commercial radio). Within these bands, each broadcaster has been assigned a specific frequency. Current television signals operate under the 40-year-old NTSC standard in Japan and the United States and require a six megahertz (MH) bandwidth to send 525 lines 30 times a second.

The Japanese solution to this problem was to abandon completely the block of frequencies devoted to television and to transmit HDTV over direct broadcast satellite (DBS). Using a single satellite, the Japanese could broadcast undistorted pictures nationwide. The broadcast system that they developed, called MUSE,, is based on a multiple Nyquist sampling encoder system that compacts all the necessary information into an eight MHz bandwidth. The Japanese plan gradually to introduce HDTV broadcasts for a few hours a day beginning in 1990 and maintain both traditional and HDTV broadcasts. A major drawback of the MUSE system is that it is incompatible with existing TV sets; consumers will need to buy new HDTV equipment while maintaining their current equipment for ordinary viewing (Japan Finance Institute, 1989).

***The early setting of standards and the elimination of uncertainty over what broadcast format would be adopted have been major contributions of the Japanese government to the development of HDTV.***

The early setting o:f standards and the elimination of uncertainty over what broadcast format would be adopted have been major contributions of the Japanese government to the development of HDTV. Since setting their own broadcast standards, the Japanese have attempted to get acceptance of the MUSE system worldwide. In a meeting with the Consultative Committee for International Radio Telecommunications, Japan proposed to make its 1,125 line/60 hertz DBS MUSE system the global standard for HDTV. This proposal was met with considerable resistance from the United States and Europe, as it was felt that Japanese firms would have a major competitive advantage in the production and sale of HDTV broadcast and reception equipment if the Japanese format was adopted.

The Europeans, like the Japanese, have decided to solve their bandwidth problem by broadcasting via satellite. They are proposing a gradual approach to the introduction of HDTV by trying to cram more information into existing broadcast signals that require only an external converter to display the unproved picture on current TV sets. They hope to broadcast HDTV by 1997.

In 1984—the same year the Japanese government and firms agreed upon their MUSE transmission standard-a number of committees within the U.S. were formed by such groups as the Electronic Industries Association, the Institute of Electrical and Electronics Engineers, the Society of Motion Picture and Television Engineers, the National Association of Broadcasters, and the National Cable Television Association.

On September 1, 1988, the FCC decided that whatever HDTV format is adopted in the United States must be backwardly compatible with existing televisions, and the broadcast standards must be available equally to terrestrial, satellite, and cable broadcasters.

Both the Europeans and Americans are hoping that selecting non-compatible broadcast standards will give their own firms an advantage in their domestic marketplaces. Just how much of an advantage they will have in developing new systems to meet this distinctive broadcast standard remains to be seen.

***Both the Europeans and Americans are hoping that selecting non-compatible broadcast standards will give their own firms an advantage in their domestic marketplaces.***

## Policy Directions and Implications

*The Japanese have demonstrated the effectiveness of a public and private infrastructure that supports improvements and innovations in manufacturing capabilities.*

The Japanese have demonstrated the effectiveness of a public and private infrastructure that supports improvements and innovations in manufacturing capabilities. High quality, low costs, and short cycles for production and product development have become the hallmarks of Japanese production. That performance is based on the effective mobilization of economic, organizational, cultural, and technical resources. And key to that mobilization is the ability to combine a cooperative spirit with an intensely competitive environment in the domestic marketplace. Firms are driven to improve continuously. In the words of an eminent early observer of Japanese firms:

> The combination of this cooperative spirit, coupled with the fierce competition in their domestic environment, drives Japanese companies to accept lower profitability and to search continuously for opportunities to improve performance throughout the manufacturing organization: improved equipment, better systems, higher worker skills. This grassroots activity is nourished by the best managerial talent available. No magic formulas are involved, just steady progress in small steps, paying attention to manufacturing fundamentals, patiently laying the foundations that will allow them to exploit future opportunities, always pressing against the boundaries of what one can do, and persistently looking for the opening, the crack in the competitive resistance that allows one to break out (Hayes, 1981).

*Greater coordination and focused effort will be necessary if the U.S. is to regain its former leadership role in high-technology industries.*

### *Public and Private Sector Roles in Managing Technology*

Greater coordination and focused effort will be necessary if the U.S. is to regain its former leadership role in high-technology industries such as consumer electronics and semiconductors. The role of the government in that development is a hotly contested issue. Some people believe that the role of the government should be strictly limited while others see an expanded role for the government in a highly competitive global economy. This must remain an abstract and sterile debate, however, unless it is linked to specific strategies for responding to challenges to U.S. manufacturing performance.

While the effective management of technology is primarily the responsibility of the firms themselves, several factors outside of the firm affect the ways in which firms manage technologies internally. These factors have to do with the external environment in which the firms operate, and may be influenced positively or negatively by government policy. On the microeconomic level, it is particularly important to develop policies that address:

1. insufficient investment in risky new technologies;

2. the role of defense spending in providing "safe havens" for U.S. firms;

3. a shortage of engineers and trained workers in key design and manufacturing disciplines; and

4. inadequate manufacturing capabilities among smaller suppliers in the design and manufacture of parts for larger products and systems.

***Several factors outside of the firm affect the ways in which firms manage technologies internally. These factors may be influenced positively or negatively by government policy.***

## *Shared Manufacturing*

One way to lower the long-term risk in new technologies is to spread the investment and risk among firms through shared manufacturing facilities. The vision of the future here, Assistant Commerce Secretary Bruce Merrifield told the Conference Board's R&D Conference in 1987, "is that a plant will make hundreds of different products for different companies in different industries: it will be continually reprogrammable to make new things and modify the old, with sister plants around the world that can be satellite programmed to make the same thing tomorrow." American companies are going to have to collaborate, because "we have to be doing our own manufacturing" and "almost no company has the total skills, resources, and risk competence to undertake these flexible systems by themselves... Shared manufacturing will happen with or without us" (lecture, March 1987).

***One way to lower the long-term risk in new technologies is to spread the investment and risk among firms through shared manufacturing facilities.***

But shared manufacturing, Merrifield argues, will demand modifications of the antitrust laws. Merrifield. who led the fight to push through the Cooperative R&D Act of 1984 that modified antitrust laws to permit cooperative research among competing companies and limited R&D partnerships, believes that the Act did not go far enough. He believes that further modification of antitrust law is necessary in order to permit shared manufacturing. Merrifield has now turned his attention to Section 7 of the Clayton Act, which prohibits mergers and acquisitions that may substantially lessen competition or tend to create monopolies. He hopes to eliminate obstacles to joint investments by companies in flexible manufacturing systems.

Opponents of liberalizing the antitrust laws believe that any further changes will reduce competition among domestic firms. As part of its competitiveness legislation, the Reagan Administration proposed five bills in 1987 aimed at modifying antitrust law. The legality of shared manufacturing is a vast gray area: it is not yet certain under what circumstances production sharing would be permitted in the future.

***The cost of U.S. capital is estimated to be two to three times greater than in Japan and Germany.***

The Commerce Department has focused much of its attention on promoting shared manufacturing among small firms, which, the Department believes, are particularly vulnerable to foreign competition. Moreover, many feel that the high cost of capital and lack of manufacturing expertise deters many small entrepreneurial firms from introducing new products. The cost of U.S. capital is estimated to be two to three times greater than in Japan and Germany. This poses an impediment to plant construction, particularly since investment tax incentives have been eliminated under the new tax bill.

***The hope is that shared manufacturing will make it more attractive for firms to manufacture in the United States.***

The hope is that shared manufacturing will make it more attractive for firms to manufacture in the United States. Such South Korean manufacturers as Goldstar and Samsung began by licensing technology from Japanese and American firms for products at the low end of the consumer electrical and electronics market. Only now are they producing their own designs under their own brand names. Says Merrifield, "Small companies need to be able to scale up production rapidly in order to penetrate global markets quickly. But right now it is easier to license the technology abroad or to go over to Korea or Japan rather than produce it yourself (interview, July 1987).

The pressure to create new products, and get them to market before competitors, has made it exceedingly difficult for firms to reap the benefits of mass production and harvest profits on mature products before they become obsolete. "It is no longer viable to build a dedicated plant that will be obsolete in three to five years anyway," says Merrifield. Flexible systems will make it possible to extend the product life cycle, "because they can continually be upgraded with new software and components." He adds: "Substantially accelerated investments will be required, as many products and process life cycles collapse to less than five years and make redundant, underfunded individual efforts less competitive" (interview, July 1987).

This vision of the future of manufacturing is shared by others. William C. Norris (1987). former chairman of Control Data Corporation, proposes a network of regional computer-aided design and computer-integrated manufacturing centers. The 10 initial centers that Norris proposes would be built over seven to eight years at a cost of about $80 million each. He envisions that they would eventually be turned over to the private sector to be operated as for-profit businesses.

Norris proposed that the estimated $800 million total cost of the centers be paid for through a combination of federal, state, and private funds. Given the high risk and the need to move rapidly in developing the centers, a large percentage of the money would have to come from the government, he says. For his part, Merrifield hopes that shared manufacturing can be developed by the private sector alone. He thinks that the federal government should nurture the idea, but not pay for it. It will probably be necessary for the government at both the state and federal levels to play a key role in financing such shared efforts, particularly if it involves improving the capabilities of smaller firms.

***William C. Norris, former chairman of Control Data Corporation, proposes a network of regional computer-aided design and computer-integrated manufacturing centers.***

Seven leading computer and semiconductor firms have recently announced plans to invest up to $500 million to build a large shared semiconductor facility to produce critical components for computers. They will begin production of dynamic random access memories (DRAMs) based on designs licensed from IBM. The new joint venture, called U.S. Memories Inc. includes such computer giants as IBM, DEC, and HP as well as chip makers-Intel Corporation, National Semiconductor, and Advanced Micro Devices. The Japanese currently control 90 percent of the market for one megabit DRAMs, and it is hoped that U.S. Memories will be able to gain five percent of the $8 billion DRAM market in three to four years (Hill and Miller, 1989: 1).

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## *Defense Industrial Base Initiatives*

Concerned over the erosion of the U.S. industrial base, the Department of Defense has developed programs to improve U.S. manufacturing and its effectiveness through technology development, education, training, and technology transfer. DOD programs have played an important role, with other federal initiatives, in the development of robotics, computer controlled machine tools, and advances in computer technology itself.

The DOD Manufacturing Technology (ManTech) programs have achieved effective results on focused projects. New efforts are underway at the DOD in evaluating the potential for simultaneous engineering-a new method which would aid in effectively linking design and manufacturing in permitting all the elements of product and manufacturing systerns design to be considered at the outset of a project. Despite the notable achievements of these efforts, they have not addressed the broader issues of technology development and the preparation of skilled personnel to design, implement, and manage new processes and facilities.

***Some astute DOD officials at DARPA and the Institutefor Defense Analysis (IDA) have been deeply concerned that the further erosion of the U.S. industrial base would seriously compromise our defense preparedness.***

If the U.S. industrial base is to be improved, either resources will have to be shifted out of the DOD, or the DOD itself will have to play a direct role in shifting funds into programs that would directly improve the industrial base and capabilities of the nation. There is evidence that such a shift may be taking place. Some astute DOD officials at DARPA and the Institute for Defense Analysis (IDA) have been deeply concerned that the further erosion of the U.S. industrial base would seriously compromise our defense preparedness. Just how far the DOD will go in supporting programs to improve the basic infrastructure and manufacturing capabilities of the nation remains uncertain.

A recent attempt to formulate this kind of coordinated development program in the United States is an initiative spearheaded by the DOD in response to the deteriorating commercial and technological state of the U.S. semiconductor industry. Sematech-a consortium of U.S. semiconductor producers-was basically organized by the DOD, which is also the agency designated to provide the federal government's half of the consortium's $1.5 billion funding over six years. Such a government initiative is unprecedented in U.S. history and seems clearly a forerunner of new policy initiatives, including funding and other commitments for HDTV by civilian agencies of the federal government that are now being debated.

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## Precompetitive Strategic Alliances

Many countries have come to view strategic alliances as an effective institutional mechanism for developing new technologies as well as for commercializing them. The strategic and policy issues raised by these alliances are far-reaching and emphasize the perceived need for speed of development, integration of diverse technology, and extremely rapid maturation of the production processes which are dominant in today's high-technologies. There are several recent prominent examples of countries trying to build strategic alliances among firms in order to improve national or regional competitive postures. Japan's MITI is commonly credited with coordinating and integrating a variety of industrial activities that have resulted in notable commercial successes. Attempts to follow this model in Europe have included the

ESPRIT and EUREKA programs sponsored by the European Economic Community.

But government support for research and development in the absence of strong companies committed to commercializing the technologies for the consumer market will not achieve the desired result of improving the competitive position of U.S.-based firms. Whether Zenith, AT&T or other U.S.-based firms will be able to compete in the long run in the commercialization of HDTV for the production of the new generation of televisions depends upon their willingness to invest time and resources. Precompetitive ventures can help in making basic technological breakthroughs and refining the technologies for transfer to private sector firms, but it is the firms themselves that will have to commit their own resources to creating and manufacturing products. The United States still has a highly competitive and viable telecommunications and computer industry. Firms in these industries will have to make major investments in HDTV and other new technologies in order to retain their competitive position.

***Japan's MITI is commonly credited with coordinating and integrating a variety of industrial activities that have resulted in notable commercial successes.***

Managing the risk involved and making timely investments for the development and commercialization of breakthrough technologies will be a major challenge for U.S. firms. Greater weight will have to be given to the risks involved in not making investments in key new technologies. Technology is the engine that drives the world economy now but few firms know how to manage it effectively. Bruce Merrifield, the assistant secretary at Commerce quoted earlier, warns that: "Any company that has not, or is not currently, making accelerated investments in development of advanced technology has made a strategic decision to be out of business in 5 to 10 years. The dam has broken 10 miles upstream, and they haven't heard the roar of the water yet (interview, July 19871."

***Managing the risk involved and making timely investments for the development and commercialization of breakthrough technologies will be a major challenge for U.S. firms.***

## *Education: The Key to Competitiveness*

It is now well accepted that a country's ability to compete is closely linked to its supply of engineers and skilled technical workers. This nation's failure to educate and tram skilled workers, engineers, researchers, and managers in design manufacturing disciplines is another obstacle inhibiting our competitiveness. The cultural forces and institutional incentives that help attract the best students into manufacturing, as well as the excellent preparation in science and math that Japanese children receive in secondary schools, is one of the key strengths of the Japanese economy. The U.S. will need to attract and train top students in design and manufacturing disciplines if we are to improve our competitive position in general, and more specifically in the electronics industries.

According to a study by Ramchandran Jaikumar (1986), a researcher at the Harvard Business School, two out of five workers in Japanese factories using computerized tools are engineering graduates, as compared with one out of twelve in the United States. Jaikumar found that the Japanese have 2.5 times as many computerized numerically controlled (CNC) machines, five times as many engineers and four times as many people trained to use the machines (1986:70).

***This nation's failure to educate and train skilled workers, engineers, researchers, and managers is another obstacle inhibiting our competitiveness.***

This presents a major challenge to the American educational system to meet growing future demands for well educated scientists, engineers, and workers who will staff the nation's firms. The general problems of recruiting, educating, and retaining these workers have been described in an excellent recent study by the U.S. Congress Office of Technology Assessment ( 1988). As the report amply demonstrates, the problems begin in the elementary schools, which suffer from chronic shortages of good mathematics and science teachers. In the high schools, too few students receive the preparation which would enable them to succeed in science and mathematics programs at the university level.

## The Teaching Factory

One of the important missing elements in university undergraduate and graduate education is the lack of real design and factory experience. A few universities now offer extensive industrial participation, on-campus laboratories, co-op programs, factory internships, and off-campus satellite programs at manufacturing sites. However, such programs are a rarity in U.S. engineering education. The next step toward improving the education and training of engineers is the "teaching factory"-a new concept to bridge the gap between research and practice.

***The next step toward improving the education and training of engineers is the "teaching factory"—a new concept to bridge the gap between research and practice.***

Manufacturing has been compared to medicine in that both fields incorporate principles and practice. Manufacturing decisions, like medical judgments, are not entirely analytical decisions but incorporate human judgments involving personnel, organizations, economics, and technical resources. Because the factors that influence manufacturing decisions are multifaceted and complex, they are difficult to convey in the classroom or laboratory alone. Classroom experience cannot replicate the pressure of providing high-quality/low-cost products in a timely fashion, anymore than one can replicate the life and death pressure of the operating table.

The teaching factory, like the teaching hospital, might provide a setting to unite this practical knowledge with problem-solving skills. Exposure to design, implementation, integration, and evaluation problems in real production settings may be the way to bridge the gap between theoretical knowledge and its application.

The concept of the teaching factory has been linked to shared manufacturing and proposed as an effective means to tram students in manufacturing disciplines. The Department of Commerce hopes to help set up demonstration projects at several U.S. schools, and Texas A&M already has plans for one. The Institute for Manufacturing Systems, a state-chartered organization that is part of the Texas Engineering Experimental Station, is planning to establish seven shared-manufacturing facilities throughout the state.

*Exposure to design, implementation, integration, and evaluation problems in real production settings may be the way to bridge the gap between theoretical knowledge and its application.*

Modeled after university teaching hospitals, the Texas A&M teaching factory would provide training in automation technology for undergraduate and graduate students, industrial engineers, and technicians, and would accept trainees from industry in a two- to four-year residency program. The other six proposed facilities would be located in six of Texas' 28 designated development districts and would foster shared manufacturing by small- and medium-size firms.

The Institute for Manufacturing Systems expects to focus its efforts on three sectors: electronics, plastics, and sheet metal. It is seeking funds from the Commerce Department to carry out a feasibility plan and to survey potential users of shared manufacturing on their needs and willingness to participate. They expect to have their first shared facility at Texas A&M up and running within the next two years.

*If teaching factories are to have an important impact on the competitiveness of the nation they will have to be initiated on a national scale at key technological universities.*

The exact form that the teaching factory will eventually take is still largely undefined, but serious attention is now being given to the concept. If teaching factories are to have an important impact on the competitiveness of the nation they will have to be initiated on a national scale at key technological universities. Investment by industry, federal and state governments, and research and educational institutions will be necessary for their success.

In the near future, small entrepreneurial firms may be able to use these shared manufacturing facilities and teaching factories to create and test-manufacture new products. The centers may also be used to help prepare the next generation of manufacturing specialists.

## *Conclusions*

Making strategic investments in key new technologies is the linchpin for the development of new products and processes. The short-term orientation of U.S. firms and their unwillingness to commit resources to the development and commercialization of new technologies is a critical factor in explaining the failure of U.S. firms to compete in the fast changing electronics industry. If the U.S. is to succeed in reentering consumer electronics-r indeed, if U.S. companies are to succeed in any highly competitive industry in the future-a better environment will have to be created to evaluate the risks of making major investments in new technologies.

***If U.S. companies are to succeed in any highly competitive industry in the future, a better environment will have to be created to evaluate the risks of making major investments in new technologies.***

The success of Japanese and European firms in the development of HDTV and, in the Japanese case, the early adoption of new broadcast standards, have already positioned these firms to be able to reap the lion's share of the profits that may be generated by the sale of HDTVs over the next decade. It will require unprecedented private and public sector coordination in the U.S. and, most importantly, major commitments from heretofore reluctant corporations, to overcome this lead. But much rests on such an effort.

The transmission, storage, processing, and reception of HDTV signals will increasingly be carried out using digital computer architecture. HDTV, as well as computers, will depend on the development of effective embedded architectures which perform complex operations at very high speed. The challenge for U.S. computer manufacturers, as well as U.S. defense electronics manufacturers, will be to find ways to produce efficient computing technologies in a real-time, cost-competitive environment. HDTV could be the first step in a much wider competition for high technology products in the computer, telecommunications, and defense electronics industries.

***Increasingly the U.S. government will have to cooperate in providing long-term funding, assist precompetitiue joint ventures to develop key new technologies, and help to set new technical standards.***

Government has an important role to play in creating the basic infrastructure for the entire technology base of the nation through support for education, including teaching factories and shared manufacturing facilities, and basic research and development. Increasingly the U.S. government will have to cooperate in providing long-term funding, assist precompetitive joint ventures to develop key new technologies, and help to set new technical standards.

The private sector has an equally critical role to play in the development and commercialization of new products and processes. The financial sectors, as well as the firms themselves, must find more effective ways of evaluating the risks involved in committing resources to the development of important new technologies. As the costs of those investments goes up, and the time between major new investments shortens, this will prove to be a major challenge for firms. However, failure to make investments in strategic new technologies will undermine their long-term viability as manufacturers as well as the competitive position of the nation.

***Failure to make investments in strategic new technologies will undermine their long-term viability as manufacturers as well as the competitive position of the nation.***

# Bibliography


Adams, John. "The Price of Might." *IEEE Spectrum*, November 1988.

Clark, Kim B. "Project Scope and Project Performance: The Effect of Parts Strategy and Supplier Involvement in Product Development." Division of Research, Harvard Business School, working paper series 88-069.

Clark, Kim B., W. Bruce Chew, and Takahiro Fujimoto. "Product Development in the World Auto Industry: Strategy, Organization and Performance." Division of Research, Harvard Business School, working paper, no date.

Cohen, Stephen S. and John Zysman. "Manufacturing Innovation and American Industrial Competitiveness." *Science*, Vol. 239, March 1988.

Council on Competitiveness, *Picking Up the Pace: The Commercial Challenge of American Innovatfon*. Washington, D.C., no date.

Dore, Ronald. *Flexible Rfgfdftfes: Industrial Policy and Structural Adjustment in the Japanese Economy, 1970-I 980*. Stanford University Press, 1986.

Dunning, John. *Multinational Enterprises, Economfc Structure and International Competftfueness*. *New* York: John Wiley Publishers, 1985.

Electronic Industries Association. "Electronics Foreign Trade Five-Year Summary." Washington, D.C., 1988.

____________. "Electronics Foreign Trade," December 1988.

Ferguson, Charles H. "From the People Who Brought You Voodoo Economics." *Harvard Business Review*, May/ June 1988.

Gilder, George. "The Revitalization of Everything: The Law of the Microcosm." *Harvard Business Review*, March/April 1988.

Hacklish, Carmela S. "International Technical Cooperation in Semiconductor Industry: Private Sector Linkups." in Herbert I. Fusfeld & Richard R. Nelson, ed., *Technical Cooperatfon and International Competftfueness*. Center for Science and Technology Policy, Rensselaer Polytechnic Institute, April 1988.

Hayes, Robert H. "Reflections on Japanese Factory Management." *Harvard Busfness Cases, 1981.*

Hill, G. Christian and Michael W. Miller, "Re-Entry Vehicle: Computer Firms Make Bold Pitch To Retake Market Lost to Japan." *Wall Street Journal*, June 22, 1989, p. 1.

Jaikumar, Ramchandran. "Postindustrial Manufacturing." *Harvard Business Review*, November/December 1986.

Japan Economic Institute. "Developing Advanced Television: Industrial Policy Revisited." *Japan Economfc Institute*, Report No. 2A, January 13, 1989.

Japan External Trade Organization. *Cooperation Between American and Japanese Firms, Cases of Industrial Cooperation In 1985*. Tokyo: JETRO, 1985.

Johnson, H. Thomas and Robert S. Kaplan. *Relevance Lost, The Rise and Fall of Management Accounting*. Boston: Harvard Business School Press, Boston, 1987.

Landau, Ralph and George N. Hatsopoulos. "Capital Formation in the United States and Japan," in Ralph Landau and Nathan Rosenberg, eds., The *Positive-Sum Strategy, Harnessing Technology for Economic Growth*. Washington, D.C.: National Academy Press, 1986.

Mandell, Mel. "U.S. Chips Are Down, Japanese Maintain Dominance in Key Components." *High Technology Business*, March 1989.

Merrifield, Bruce. Lecture at Conference Board Conference on R&D Technology, New York, March 3, 1987.

____________. Interview, July 1987.

Mitchell, Graham R. and William F. Hamilton. "Managing R&D as a Strategic Option." *Research-technology Management,* Vol. 31, No. 3. May/ June 1988.

Nathan, Robert R. *Television Manufacturing in the United States: Economic Contributions— Past, Present, and Future*. Washington, D.C.: Robert R. Nathan Associates, November 22, 1988.

National Research Council. *The National Challenge in Computer Science and Technology*. Washington D.C.: National Academy Press, 1988.

Norris, Wffliam C. "Become Competitive? Here's How." *The New* York *Times*, August 19, 1987.

Ozawa, Terutomo. "Japan," in John Dunning's, *Multinational Enterprises, Economic Structure and International Competitiveness, New* York: John Wiley Publishers, 1985.

Rosenbloom, Richard R. and Michael A. Cusumano. "Technological Pioneering and Competitive Advantage: The Birth of the VCR Industry." *California Management Review,* Vol. XXIX, No. 4, Summer 1987.

Sanderson. Arthur C. Interview, February 1989.

Sanderson, Susan Walsh. "The Vision of Shared Manufacturing." *Across The Board,* December 1987.

__________ "Strategies for New Product Design and Product Renewal." *Best Paper Proceedings*. Washington, D.C.: Academy of Management, 1989.

Schlender, Brenton R. "Next Project." *The Wall Street Journal,* October 13, 1988.

Takeuchi, Hirotaka and Ikujiro Nonaka. "The New New Product Development Game." *Harvard Business Review*, January/February 1986.

*TV Digest*, Vol. 28, No. 39, September 26, 1988.

____________, Vol. 28. No. 44. October 3 1, 1988.

U.S. Congress. Office of Technology Assessment. Educating *Scientists and Engineers: Grade School to Graduate School.* Washington, D.C.: 1988.

U.S. Department of Commerce, International Trade Administration. U.S. *Industrial Outlook 1989.* Washington, D.C.: January 1989.

U.S. Department of Commerce, International Trade Commission. Imports *Under Item 806.30 and 807.00 of the Tariff Schedules by the United States, 1982-1985.* Washington, D.C.: December 1986.

U.S. Department of Commerce, International Trade Commission. *United States Trade.* Washington, D.C.: October 1986.

**Yoder,** Stephen Kreider. "U.S. Firm Takes on Japan Patent Issue." *The Wall Street Journal,* October 13, 1988.