

Strategic Impacts of High Definition Television
for U.S. Manufacturing

A Report to the National Center for Manufacturing Sciences

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**NCMS AND ACTIVE MEMBERS
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Editor's Note

In a few cases explanatory material or comments upon recent events have been added by the editor of this report. These comments are enclosed in brackets, and have the following format: {..... -ed.} They should not be taken as Dr. Hart's thoughts.

1.0 EXECUTIVE SUMMARY

The prime charter of the National Center for Manufacturing Sciences (NCMS) is to improve U.S. manufacturing. The debate over U.S. participation in high definition television (HDTV) markets is linked to the NCMS charter because the debate has focused on the importance of creating research and development consortia and the need to include foreign-owned firms in those consortia. The need for foreign participation in U.S.-based consortia arises from the extreme weakness of U.S. firms in consumer electronics. Only one U.S. firm -- Zenith -- remains a major producer of televisions. Two foreign firms -- Thomson of France and Philips of the Netherlands -- control about 38 percent of the U.S. market for televisions.¹ Japanese firms totally dominate U.S. markets for VCRs, video cameras, audio systems, and compact disk players. There is virtually no alternative to a short- to mid-term strategy of partnerships with foreign firms if the United States is to participate in the large projected markets for HDTV equipment. But only those foreign firms willing to put a major portion of their research, development, and production in the United States should be allowed to join U.S.-sponsored consortia. A viable long-term strategy for maintaining U.S. competitiveness in electronics has to include the building up of indigenous technological and manufacturing capacity in high-volume, low-cost electronics.

The major question for this report is: Is HDTV the proper vehicle for U.S. reentry into consumer electronics markets? While there are still some uncertainties about the answer to this question, the prospects for using high definition television as the appropriate vehicle seem to be rather good. The main reasons for choosing HDTV as the vehicle for reentry are:

- sales of video products are roughly half of the total consumer electronics market -- thus any significant reentry into consumer electronics is likely to involve video products;

- HDTV circuitry will be more complex than NTSC circuitry. {NTSC stands for National Television Standards Committee, and denotes the standard created more than thirty years ago which is used in the U.S. and Japan. Much of the rest of world television operates under more recent standards. -ed.} For example, it will require random access memory (RAM) devices for the storage of video data (NTSC sets did not require RAMs until the introduction in 1989 of improved definition televisions or IDTVs). U.S. semiconductor manufacturers maintain certain advantages in HDTV-related technologies (such as fast microprocessors and digital signal processors) and could benefit from the increase in demand for

1. The terms U.S. firm and foreign firm will refer to the ownership and not the location of firms in this report.

random access memory devices that will result from the sale of HDTV equipment;

-the building of HDTV equipment for mass consumer markets will help U.S. electronics manufacturers maintain and improve their ability to build all types of high volume, high quality, low price electronic equipment;

-the availability of inexpensive but high-quality video displays will continue to be an important factor in the competition for world computer and telecommunications equipment markets; and

-the development of HDTV technology will help to justify the linking of households to national broadband telecommunications networks.

This report is organized in seven major sections. Section 3.0 deals with present market status and trends in consumer electronics. Section 4.0 lays out some possible scenarios for the development of HDTV technologies, products, and markets. Section 5.0 provides market projections for future HDTV products given several scenarios selected from Section 4.0. Section 6.0 considers the technological and human resources linkages between HDTV and consumer electronics, on one hand, and the other industries in the electronics complex, on the other. The purpose of Section 6.0 is to demonstrate the importance of participating in HDTV markets to maintain U.S. competitiveness in electronics. Section 6.0 argues that such competitiveness is vital for U.S. economic competitiveness and national security. Section 7.0 provides recommendations for policies to promote U.S. participation in HDTV markets.

element in their present and future competitiveness because microelectronics are a major focus for innovation in both product and process technologies for the rest of the economy. In addition, microelectronics is subject to "virtuous circles" in which decreasing prices lead to a rapid growth in demand which makes further price reductions possible.⁴

The abandonment of consumer electronics markets was partly the result of the failure of U.S. consumer electronics manufacturers to meet the intense competition from Japan. While ill-advised trade policies played a major role in the problems of U.S. consumer electronics firms, unwise decisions about product and process technologies on the part of the managers of U.S. firms were probably just as important. U.S. firms were late in introducing transistors, and later integrated circuits, into their consumer products. They were late also in adopting a variety of automated assembly techniques in manufacturing. With the advent of HDTV, the waning U.S. presence in consumer systems becomes more threatening because of the possible convergences between the underlying technologies of computers, telecommunications equipment, and consumer electronics, especially those embodied in VLSI (very large-scale integrated) circuits.⁵

This is why a number of major U.S. electronics companies now want a greater U.S. presence in consumer electronics.

Researchers at BRIE have argued elsewhere that future reentry of U.S. firms into consumer electronics markets, possibly through the vehicle of HDTV, will be a major factor in maintaining U.S. strength in electronics and therefore a key to increasing U.S. competitiveness overall.⁶ The major question for this report is to answer the following question: Is HDTV the proper vehicle for U.S. reentry in consumer electronics markets? While there are still some uncertainties about the answer to this question, the prospects for using HDTV as the appropriate vehicle seem to be rather good. The main reasons for choosing HDTV as the vehicle for reentry are:

4. See Michael Borrus, Competing for Control: America's Stake in Microelectronics (Cambridge, MA: Ballinger, 1988).

5. Jeffrey A. Hart, "The Consumer Electronics Industry in the United States: Its Decline and Future Renewal," Chapter 3 of The U.S. Electronic Industry Complex, a report to the U.S. Congress, Office of Technology Assessment (Berkeley, CA: Industry and Trade Strategies, October 18, 1988).

6. Jeffrey A. Hart and Laura Tyson, Consumer Electronics, HDTV, and the Competitiveness of the U.S. Economy (Berkeley, CA: Berkeley Roundtable on the International Economy, February 1, 1989).

-sales of video products are roughly half of the total consumer electronics market -- thus any significant reentry into consumer electronics is likely to involve video products;

-HDTV circuitry is complex and uses more digital circuitry than NTSC circuitry -- and the additional demand for digital signal processors and memories that will result from the growing sales of HDTV equipment can help to develop state-of-the-art semiconductor manufacturing facilities;-

-inexpensive but high-quality video displays are important factors in the competition for world computer and telecommunications equipment markets; and

-there will be important benefits for the U.S. telecommunications infrastructure from development of HDTV technology as it will help to justify connecting households to national broadband telecommunications networks.

3.0 PRESENT MARKET STATUS AND TRENDS

This section will assess the importance of consumer electronics for the electronics complex and the potential future role that can be played by HDTV products. It starts with a discussion of the current markets for consumer electronics and sets these within a broader context of the markets for electronics generally. Consumer electronics markets are significant not only because of the revenues and employment they generate but also because of their linkages with other electronics markets. This section documents the overall weakness of U.S. firms in consumer systems, especially in televisions, VCRs, and video cameras, and the strength of Japanese firms in these products. It shows that U.S. weakness has led to a high level of imports of consumer equipment and to large inflows of investment by foreign firms to secure a manufacturing base in the United States. Manufacturing by foreign firms in the United States is limited almost exclusively to tubes and cabinets. The advanced electronic circuitry for consumer systems manufactured by foreign firms in the United States is imported primarily from Japan and Europe. Less advanced and relatively standardized circuits are increasingly imported from Korea and Taiwan.

3.1 The Importance of Consumer Electronics Within The Electronics Complex

According to Dataquest, worldwide production of electronic equipment was 674 billion dollars in 1988 (see Table 1). Approximately 20 percent of that figure, or about 136 billion dollars, was accounted for by production of consumer electronic equipment. Whereas 33.4 percent of Japanese electronics production was accounted for by consumer equipment, only 6.7 percent of North American production was in consumer goods. The United States accounted for 40 percent of global electronics production in 1988, Japan for 22 percent. In contrast, Japan accounted for 36 percent of global production of consumer electronics, the United States for only 13 percent (see Figures 1 and 2).

The global market for electronics was around 461 billion dollars in 1987 (see Table 2). The Japanese share of the global market for electronics increased from around 21 percent in 1984 to around 27 percent in 1987. Part of this increase in Japan's global share in electronics was the result of rapid growth of consumer markets worldwide, in which Japanese products -- especially VCRs -- were clearly dominant.

There is a tendency in the United States to discount the importance of consumer electronics because of the mistaken impression that the technology underlying consumer electronics is not important for the rest of electronics. What the global market figures illustrate is that consumer electronics is a very important part of the world electronics market, thanks to its size and rapid growth, and that some of Japan's competitive success in electronics in recent years has been the result of its strength in consumer electronics production.

3.2 The Market for Consumer Electronics In the United States and Europe

The consumer electronics market in the United States increased from about 8 billion dollars in 1977 to over 30 billion in 1987 (see Table 3). The largest single submarket within consumer electronics is color televisions -- 6.3 billion dollars in 1987, or about 20 million units -- closely followed by the market for VCRs (VCRs) at 5.1 billion dollars. Projection television is a relatively new product. The market for projection televisions is still much smaller than that for conventional televisions, but it is a rapidly growing one. Televisions, VCRs, and camcorders made up around 42 percent of the total market.

The European market for color televisions was around 9.5 billion dollars in 1986, or about 15.9 million units. Britain, France, Germany and Italy all saw purchases of over 2 million units each in 1986. Together, those four countries accounted for 70 percent of the total European market for televisions. 7.2 million VCRs were sold in Europe in 1986, the total value of which was 5.1 billion dollars. Again, Britain, France, Germany and Italy were around 70 percent of the total market.⁷

The United States and Europe are the two largest markets for consumer electronic equipment, although Japan's domestic market is also sizable. As we shall see below, the weakness of U.S. firms means that most of the consumer equipment sold in the United States is either imported or manufactured locally by foreign firms. Most of the local manufacturing is assembly only. In Europe, the situation is similar. The main difference between Europe and the United States is that two European firms with global operations were able to survive in the presence of Japanese and other Asian competition: Philips and Thomson. These two firms produce a substantial number of televisions in Europe and in North America. Thomson markets and assembles Japanese-designed VCRs for both markets; Philips has the capability to manufacture its own VCR designs.

3.3 Japanese Production of Consumer Electronics

Japanese production of consumer electronic equipment rose dramatically between 1967 and 1987 (see Table 4 and Figure 3). In 1967, Japan produced 1.3 million color televisions. Production of color televisions peaked in 1985 at 17.9 million units but fell back to around 14 million in the next two years.⁸ Because Japanese firms were able to dominate VCR and audio equipment markets in the 1980s, they were able to increase overall production of consumer electronics even though the production of

7. Consumer Europe 1988 (London: Euromonitor, 1988), pp. 394-9.

8. Facts and Figures on the Japanese Electronics Industry (Tokyo: Electronic Industries Association of Japan, 1988), p. 51.

televisions stabilized at around 700 billion yen (see Figure 3a). VCR production in value terms first exceeded production of televisions in 1981. By 1987, VCR production was almost twice the value of television production. Overall production of consumer electronics continued to increase slowly in the 1985-7 period but exports declined and imports rose significantly after 1986.

The reduced trade surplus in Japanese consumer electronics was due mostly to increasing competition from production in the newly industrializing countries (NICs) of Southeast Asia, especially Korea, Taiwan and Singapore. The largest increase in Japanese imports from Southeast Asia between 1985 and 1987 was in audio cassette recorders, but large increases also occurred in color televisions and VCRs. Most of the production in Southeast Asia is by subsidiaries of Japanese firms or by local makers under OEM contracts.⁹

Korea is somewhat of an exception in this regard, with firms like Lucky-Goldstar, Samsung, and Daewoo producing their own designs under their own labels. Korea is beginning to move its product mix up toward the high end. The Koreans, for example, have begun their own program to develop HDTV technologies funded at around 200 million dollars.

3.4 Trade In Consumer Electronic Equipment

The world market for televisions was around 70 million units in 1988 (see Figure 4). Europe and the United States accounted for over half of the demand for televisions. Japan was the third largest market for televisions, followed by China. High consumption of televisions and VCRs in the United States and Europe (and limited local production only of televisions) means that these two regions are major net importers of consumer electronics equipment, mainly from Mexico, Japan, and Southeast Asia. The United States and Europe export very little to Japan in consumer electronics (see Figure 5). Most of Japan's imports of consumer electronics originate in Southeast Asia or other low-wage regions.

The U.S. trade deficit in consumer electronics has been increasing steadily. In 1987, for example, the United States had a trade deficit of 13.6 billion dollars in consumer electronics, up from 7.9 billion in 1983.¹⁰ Japanese estimates show that the Japanese trade surplus with the United States in consumer electronics was 1.9 trillion yen in

9. Japan Electronics Almanac 1989 (Tokyo: Dempa, 1989), ch. 9.

10. EIA, Electronic Market Data Book (1988), p. 124.

1987 (see Table 5), and that the United States is by far the most important single destination for Japanese exports.¹¹

Japanese exports of consumer electronics were hurt by the revaluation of the yen in 1985. In 1985, those exports were around 3.5 trillion yen. By 1987, exports had dropped to around 1.9 trillion yen (see Table 5). Since imports were almost negligible in Japan, even with the recent growth of imports from Southeast Asia, the trade surplus also dropped between 1985 and 1987 by about 1.6 trillion yen.

3.5 Import Penetration, Inward Foreign Investment, and Domestic Content in the U.S. Market

Import penetration (the share of imports in domestic demand) in color televisions rose from zero in 1965 to around 60 percent in 1986. The volume of color television imports dropped precipitously, beginning in 1986 (see Figure 6) from a high of 14 million units in that year to an estimated 6 million units in 1988. The drop in imports to the U.S. between 1986 and 1988 was due partly to the drop in the yen vis-à-vis the dollar, but also partly to the ramping up of production in the United States by foreign-owned (mostly Asian) firms.

Worldwide foreign investments by Japanese firms in "electric machinery" grew from 309 million dollars in 1980 to over 2.4 billion in 1987.¹² This global trend included investments in consumer electronics production facilities in the United States, primarily for the manufacturing of large CRTs for television sets sold in the United States and for assembly of components (see Tables 6 and 7). U.S. final assembly operations were established by Japanese firms in the following sequence: Sony in 1972, Matsushita in 1974, Sanyo in 1976, Mitsubishi in 1977, Toshiba in 1978, Hitachi and Sharp in 1980.¹³

Sony's investment in television-related research and development in the United States is the largest of the Japanese firms. Matsushita has a research and development

11. This figure is based on statistics from the Japanese Ministry of Finance as reported in the EIAJ, Facts and Figures, pp. 36-7 and 40-1.

12. Ministry of Finance data cited in EIAJ, Facts and Figures (1988), p. 24.

13. Committee to Preserve American Color Television (COMPACT), Recommended Government Policies to Promote the Evolution of a U.S. High Definition Television Industry, submission to the Subcommittee on Telecommunications and Finance of the House Committee on Energy and Commerce, Washington, D.C., February 1, 1989, p. 12.

center for video broadcasting in Burlington, New Jersey, and NEC has a research and development center for home electronics in California. But only Sony has announced funding for HDTV research in the United States -- 20 million dollars for broadcasting systems at its new research center in San Jose.¹⁴

Other foreign firms active in the United States include Thomson of France, Philips of the Netherlands, Goldstar and Samsung of Korea, and Tatung of Taiwan. A number of these firms established their presence by acquiring existing U.S. firms. Philips purchased Magnavox in 1975 and Sylvania from GTE in 1981. Matsushita purchased Motorola's television unit in 1974. Thomson's presence in the United States derives from its purchase of RCA/GE consumer electronics from GE in 1987. It has not been the policy of the U.S. government to screen or restrict inward foreign investment. One consequence of this policy is that around 87 percent of the domestic market for televisions is controlled by foreign-owned firms.

The domestic content of color televisions sold in the United States in 1988 was approximately 70 percent.¹⁵ While virtually no U.S. electronic components are used in color televisions sold in the United States, most sets include tubes and cabinets that are domestically manufactured. Thus, even though foreign firms dominate the U.S. market for televisions in terms of ownership and unit volume, there is still substantial domestic content in U.S. television production.

Several factors explain the continued role of U.S. content in televisions produced by foreign firms in the United States. One major factor is the expense and damage caused by shipping bulky items like CRTs and cabinets from distant production sites. A second factor, operating only since 1985, is the change in the yen-dollar exchange rate which favors manufacturing in the United States. A third factor, of decreasing importance in recent years, is the existence of patents for tube and glass technology held by U.S. firms. A fourth factor is the desire of foreign firms to be good corporate citizens. Their hope is that their growing manufacturing presence in the United States will be viewed favorably by the American public, and especially by policy makers.

3.6 Market Shares of Specific Firms In the U.S. Market

The U.S. market for televisions is very competitive, and is divided among a larger number of firms than is generally the case in both European and Asian markets (see Table 8 and Figure 7). The last remaining major U.S.-owned producer of televisions, Zenith, held only 13 percent of the U.S. market in 1988, down from 22 percent in

14. "Sony Expands in Silicon Valley," Dataquest Research Bulletin, May 1989, p. 1.

15. This estimate comes from Joseph Donahue of Thomson Consumer Electronics.

1977.¹⁶ The top three firms -- Thomson, Zenith, and Philips -- collectively held 50 percent of the market in 1988. Of the Japanese firms operating in the U.S. market, Sony is the most important and has gained market share vis-à-vis its main competitor, Matsushita. Sharp and Mitsubishi (MGA) have both increased their shares to over 4 percent in recent years.

The figures on market shares illustrate two very crucial points: 1) the weakness of Zenith in the U.S. market, and 2) the continuing strength of firms that were formerly U.S.-owned but were acquired by the two main European firms -- Thomson and Philips. Any workable strategy for U.S. participation in HDTV markets has to take these two points into account.

16. Harvey Industries of Athens, Texas, is U.S.-owned and manufactures around 500,000 televisions per year which are sold under the Curtis Mathes brand-name.

of purchases by consumers. This section discusses factors that may delay or accelerate conversion to HDTV signal delivery.

4.1.1.1 The Role of the Cable Programmers and Networks

There are indications that the setting of transmission standards will be speeded by the announced intention of cable programmers and networks to move ahead with HDTV transmissions via cable independently of the deliberations of the Federal Communications Commission (FCC). The FCC has jurisdiction over terrestrial over-the-air broadcasting signals but not over signals delivered by cable. The cable industry has been building its share of the total television viewing audience, at the expense of the over-the-air broadcasters, by offering better reception for people who live out of the range of terrestrial transmission towers and more choice in channels and programming (see Figure 8).

Some cable networks and programmers now see an opportunity to increase cable's share further by beating the networks and local broadcasters to high definition television. Because the extra channels on cable systems often include movies, the advantages of higher resolution in displaying movies will help to broaden the appeal of cable subscription to consumers. This is the position, for example, of Home Box Office (HBO).

4.1.1.2 The Role of the Cable Operators

The cable operators, in contrast to the cable networks and programmers, are taking a somewhat more cautious approach to HDTV. They want to be sure that investments in new delivery systems will result in greater returns. Most cable subscribers spend the bulk of their viewing time watching the local over-the-air channels and "super channels" that are available with the minimum cable fee. A smaller number pays extra for the various movie channels. The cable operators are worried that subscribers will be unwilling to pay still more to watch the same movies and programming in higher resolution. Thus, several major cable operators, most notably TCI, have come down in favor of improving NTSC signals via the Faroudja method, rather than going immediately to HDTV delivery.¹⁸

{The Faroudja organization has demonstrated picture quality improvement within the NTSC system through changes to the electronics at the receiver alone or at both the

18. Testimony of John J. Sie, Senior Vice President, Tele-Communications, Inc., on "High Definition Television and the Federal Government's Role in Developing a Competitive U.S. Industry," before the House Committee on Science, Space, and Technology, March 22, 1989.

receiver and the transmitter. This approach is completely compatible with the present day television system. -ed.}

4.1.1.3 The Role of VCRs and Video Discs

In the absence of governmental policies to accelerate HDTV programming and signal delivery, therefore, the real push for HDTV delivery in the United States is likely to come not from cable or terrestrial broadcasters but from VCR and interactive video disc markets. The watching of VCR programming competes with that of both movie theaters and broadcast and cable television for audience share. The VCR rental market has boomed in recent years with the rapid sales of inexpensive VCRs and the rapid release of movies on tape by the major motion picture studios. While many consumers are satisfied with the smaller and lower resolution images available to them with existing VCR and television technology, the VCR industry is very likely to try to grow by improving image size and resolution by moving toward HDTV. The same logic applies to the newer and smaller video disc industry. Thus, both broadcast and cable television may be driven to adopt HDTV delivery systems earlier than they might otherwise desire because of the fear of losing audience share to VCRs and video discs.

4.1.1.4 The Role of the Over-the-Air Broadcasters

Despite the pressures from cable, over-the-air broadcasters are very concerned about the expenses involved in converting their existing transmission equipment so that they can broadcast HDTV signals. The expense of doing this will depend on which transmission systems are adopted, but all alternatives seem to point to additional investments by networks and local broadcasters. The networks' additional expense may not be so great relative to current expenditures because they are already using high definition production equipment and transmitting high quality images via satellite to cable systems and local broadcasters. The local broadcasters, however, may need to buy new antennas and transmission equipment just at a time when their return on investment is insecure, owing to the encroachments of cable and VCR viewing.

For this reason, networks and their affiliated local broadcasters are looking carefully at alternatives to HDTV. One example of this is the NBC policy of advocating a phased introduction of extended definition television, prior to HDTV, via the RCA-Sarnoff Laboratories ACTV-I system. ACTV-I is an NTSC-compatible system that allows broadcasters to slightly increase picture resolution. ABC is pushing for an upgrading of NTSC broadcasts via the Super-NTSC system created by the Faroudja Laboratories. CBS is in favor of using 1125/60 production systems and has a variety of cooperative arrangements with a major Japanese producer of this equipment -- Sony. {The numbers 1125 and 60 refer to the number of picture scan lines and the picture update rate. -ed.}

convergences in displays and display circuitry between computer and consumer systems. Thus, counting on continued U.S. superiority in digital computer technology to provide a springboard for reentry into consumer systems does not seem a prudent policy. Nevertheless, there is enough argument over these matters to possibly delay the adoption of an HDTV transmission standard in the United States.

4.1.2 The Content of U.S. HDTV Transmission Standards

The content of U.S. HDTV transmission standards will help to determine how expensive it is for foreign producers to build equipment to the U.S. standard and how attractive the final HDTV products are to consumers. In addition, transmission standards will affect costs associated with the production of HDTV programs. Since program producers must make investment decisions about what HDTV production equipment to purchase years before the initiation of HDTV signal delivery, transmission standards will have a direct impact on who wins and loses in the "software" side of the HDTV business.

4.1.2.1 Why Production People Want a Single Global Standard

If one were trying to maximize benefits at the level of the world system, then there would be global uniformity in production, transmission and reception standards. In this ideal world, there would be no costs connected with converting programs from one standard to another. The people who make video images would like such a world to come into existence, but unfortunately, they are likely to be disappointed.

One important question in the selection of a transmission standard is how it will affect the overall availability of high definition program material. If this material is readily available, HDTV equipment sales will be much faster because consumers will be more interested in viewing HDTV programs. Thus, the consumers and equipment producers benefit to the degree that the choice of the transmission standard makes it more profitable for program producers to produce programs.

4.1.2.2 The 1125/60 Group

A number of production studios and networks in the United States have already invested in HDTV production equipment which uses the 1125/60 format. One national network, CBS, has committed itself to supporting the community of 1125/60 users, and played a key role in organizing the 1125/60 Group.²¹ The 1125/60 users will be hurt

21. A group of U.S. and Japanese firms, called the 1125/60 Group, was formed in June 1988, to promote the NHK production standard in the United States. The charter members of that group included: Chyron, Cinema Products, Compression Labs, Dynair Electronics, Dynatech Broadcast Group, Grass Valley Group, Hitachi America, Ikegami

if the U.S. adopts a transmission standard which requires them to pay the cost of converting their 1125/60 programs or to scrap their 1125/60 production equipment. This is not a large enough problem to justify adoption of an 1125/60 display format, but it can be expected to play a role in the political discussions over HDTV transmission standards.

4.1.2.3 The Main Alternatives to 1125/60

If 1050/59.94 becomes the display format of choice because of its easy compatibility with the NTSC format (525/59.94), then viewer acceptance of HDTV in the United States might be somewhat more limited because of the lower picture resolution of a 1050 line system in comparison with the 1125 and 1250 line systems of Japan and Europe. Thus, despite the logical advantages of 1050/59.94 as a display format for the U.S. transmission standard -- as proposed, for example, by Zenith in its Spectrum Compatible system -- there are reasons to believe that a display format for production with more scanning lines would be desirable. The display format for the production system would have the same field rate and aspect ratio as transmission and reception systems, however. The number of lines of the production display format would be set to make high-quality conversion to foreign transmission standards as inexpensive as possible.

4.2 Methods of Delivering HDTV Signals

The methods of delivering HDTV signals to households are important because these will have a major effect on the attractiveness of HDTV equipment to consumers. The choice of transmission standards and delivery methods are closely intertwined, because each major delivery method carries with it different ways of optimizing the quality of the HDTV signal. Both standards and delivery methods are also crucial considerations for receiver manufacturers, because they are important for the design of receivers and can effect the cost of producing them.

The major alternatives for delivery of HDTV signals are: 1) over-the-air broadcast, 2) cable, 3) direct broadcast satellite (DBS), and 4) fiber optics. Each of these alternatives has its respective pluses and minuses (see Table 9).

The most likely scenario for HDTV delivery in the short term, i.e., in the next 4-5 years, would be a reliance primarily on a combination of over-the-air and cable. In the mid to long term (six years or more), direct broadcast satellite and fiber optics should

Electronics, Magni Systems, NEC America, Panasonic, Panavision, Quantel, Rank Cintel, Sony Corporation of America, Symbolics Graphics, Toshiba America, Ultimatte Corporation, and U.S. JVC. See HDTV Newsletter, (July 1988), p. 13.

begin to play a more important role -- especially if cable operators and telephone services providers compete to connect fiber optics cables to homes.

Because of the high likelihood that offices and factories will be increasingly dependent on broadband telecommunications networks, there will be increasing pressure on the government from business to extend broadband network access to homes as well, independently of the use of those networks to carry video signals. The broadband network will be compared to the federal highway system in its potential role as a basic infrastructure for the transportation of information.

Too much competition from cable or direct broadcast satellite, however, might slow the building of fiber networks by telephone companies, at the expense of building a more robust and more highly interactive video-capable telecommunications network. Similarly, political resistance from local broadcasters to the move from over-the-air to satellite and fiber optics could slow the building of broadband networks. The huge expense of building the national broadband network will be a major source of controversy and could delay its completion, especially if there is low growth in the national economy. Thus, one needs to keep in mind the possibility that HDTV diffusion can be slowed by problems in delivering high-quality HDTV signals to the home. An optimistic scenario means assuming that there will be a quick transition from the reliance on transmission via over-the-air and cable to direct broadcast satellite and fiber.

4.3 The Initial and Subsequent Prices of HDTV Receivers

The initial price of HDTV equipment will be important, as it will affect the takeup rate. U.S. consumers are accustomed to relatively low prices for color television receivers. The median retail price of color Televisions sold in the United States was under 400 dollars in 1988, down markedly from the median of around 500 dollars in 1980.²² Consumers will resist paying markedly higher prices for HDTV receivers unless they see them as providing a markedly better viewing environment.

4.3.1 The Need to Appeal to the Average Consumer

There will always be some consumers who are willing to pay high prices for the latest innovations in video technology, and thus there will be opportunities for introducing products well before they have reached the prices that make them attractive to the average consumer. But if one is concerned about the spinoffs from HDTV to the rest of the economy, then these will be more significant if HDTV equipment is purchased

22. Joseph Donahue, Thomson Consumer Electronics, "U.S. Criteria for Advanced TV System," presentation to the AEA Task Force on Advanced Television, November 10, 1988.

by the average consumer. There is a possibility that HDTV will be more like projection Televisions and camcorders than like black and white Televisions or compact disk players in winning consumer acceptance because of high initial prices and performance characteristics that average consumers do not need or want (see Figure 9).

In order for HDTV to become a mass consumer product, the average consumer must be willing to pay the necessary premium for the higher resolution, wider screens, and digital stereo sound of HDTV sets.²³ Most manufacturers are betting that these improvements will have to be introduced gradually to win consumer acceptance. Thus, they will provide first improved definition televisions (IDTVs)²⁴ and then extended definition televisions (EDTVs)²⁵ before they introduce their HDTV lines.

One of the ironic consequences of the gradualist approach to moving toward HDTV is that IDTV and EDTV may prove so popular that they may delay the transition to HDTV. It is certainly the case that it will be less expensive for the over-the-air broadcasters and the cable operators to make the necessary investments for improved definition television and extended definition television than for HDTV transmission equipment, so these two groups are hoping that IDTV and EDTV will satisfy consumer needs for a long time to come (so that they can amortize their investments). Regardless of the popularity of improved definition television and extended definition television, however, the transition to HDTV will begin as soon as at least one firm builds and sells inexpensive HDTV equipment and one major medium for the delivery of video signals switches over to HDTV.

23. There are very few empirical studies on this question. One widely cited one is W. Russell Neuman, "The Mass Audience Looks at HDTV: An Early Experiment, paper presented at the National Association of Broadcasters' Annual Convention, Las Vegas, Nevada, April 11, 1988. Neuman's study suggests that people preferred the HDTV image to the NTSC equivalent, but were not willing to pay more than 100 dollars over the NTSC price to get it. The main problem with the study is that HDTV images were displayed on 18-inch and 28-inch CRTs. Many HDTV experts claim that you need a display of at least 40 inches in order to appreciate the differences between HDTV and NTSC systems.

24. An improved definition TV uses special circuitry, including frame storage devices and video image processors, to eliminate artifacts introduced in the transmission of NTSC signals to the home. It may result in higher picture resolution, but does not change the aspect ratio of the display or provide digital stereo sound.

25. Extended definition TVs may have wider screens, higher resolution, and better sound systems than NTSC TVs, but do not match the picture resolution of HDTV sets.

4.3.2 The Role of Circuitry In HDTV Prices

The circuitry for HDTVs will be more expensive than the circuitry for NTSC receivers. HDTV receivers will require some form of random access memory (RAM) for frame storage, probably on the order of 4 megabytes. In addition, HDTV circuitry will include analog-to-digital (A/D) and digital-to-analog (D/A) converters, microprocessors, digital signal processors, and image processors. This circuitry will not, in general, be embodied in separate components, but rather in a small number of VLSI (very large-scale integrated) devices. In a current NTSC color Television set that costs around 270 dollars to manufacture, only about 20-30 dollars goes into the semiconductor components for the set, i.e., less than 11 percent. The initial cost of semiconductors for HDTV sets introduced in the next few years is likely to be in the neighborhood of 400 dollars. This cost will come down to around 25-50 percent over the cost of current circuitry or around 50-80 dollars per set.²⁶ The speed at which it does this will depend on the cumulative volume of sales of HDTV circuitry for each of the firms producing HDTV circuits -- because circuitry is subject to dynamic scale economies (more commonly called "learning curves").

4.3.3 The Role of Displays In HDTV Demand

HDTV receivers will have relatively large displays, 40 inches diagonally or larger, to take maximal advantage of the higher resolution available. HDTV images on smaller displays will be better than the NTSC images, especially if fiber and satellite delivery systems are used, but perhaps not sufficiently better to justify the higher price of HDTV sets to the average consumer. Thus, HDTV receivers will be introduced initially with larger displays. Since the cost of making larger displays is generally higher than that of making smaller displays, unless there is a breakthrough in the technologies for manufacturing large displays, the percentage of total manufacturing cost accounted for by displays will be higher for HDTV sets than for NTSC sets.

4.3.3.1 CRT Displays

Cathode-ray-tube displays constitute on the average about 30 percent of the manufactured cost of NTSC sets. That is, for a set that costs about 200 dollars to manufacture, the CRT display would cost around 60 dollars. Televisions with CRT displays are increasingly referred to as "direct view" televisions, to distinguish them from projection televisions. All displays larger than 38 inches on current NTSC receivers are projection displays.

The larger televisions made and sold in the United States have larger CRTs than the average, and therefore the average percentage of manufacturing costs accounted for

26. These cost estimates were obtained by interviews with industry representatives.

by CRTs are closer to 50 percent in this country. 31-inch CRTs currently cost around 500 dollars on the open market. Next year, 35-inch CRTs will cost about the same amount. Large CRTs are sure to be used in HDTV receivers. Thomson, for example, is going to manufacture 34-inch tubes with a 16:9 aspect ratio at its plant in Marion, Ohio.²⁷

4.3.3.2 Projection Displays

Projection sets are substantially more expensive than direct-view sets because of the higher cost of the cabinet. The projection system itself is comparable in cost to the CRT in larger sets. A 52-inch projection television is retail priced typically at around 2,000 dollars per set. One can assume that the manufactured cost of a projection television is around 1,000 dollars, and that the projection display is around 30 percent of the manufactured cost or approximately 300 dollars. The projection displays in 2,000 dollar units could not be used to display HDTV images because they do not have the necessary resolution and brightness. Professional television projection systems with the necessary resolution and brightness currently retail for over 6,000 dollars per unit.

The bulkiness and relatively low quality of projection displays has been a key factor limiting the consumer acceptance of projection televisions. Projection televisions are unable to display colors correctly and with enough brightness. It is difficult for people outside a relatively narrow viewing angle to see the image. The low quality of projected images stems from the following factors: 1) the projection of NTSC images reveals the limits of picture resolution inherent in the NTSC system and 2) projection systems are not as bright as CRTs and therefore cannot produce the same degree of contrast between light and dark images. Nevertheless, the market for projection televisions grew very rapidly from a small base until reaching a plateau of over 500 million dollars in 1986 (see Table 3).

4.3.3.3 Semiconductor-Based Displays

Liquid crystal displays are highly attractive for future HDTV equipment because they may end up being less bulky and cheaper to manufacture than CRTs and existing projection systems. These displays are not likely to be commercially competitive with CRTs and existing projection systems for at least 5 years, however. There are at least three types of such displays currently under development: 1) multiplexed LCD flat panels, 2) active matrix LCD flat panels, and 3) thin-film transistor (TFT) driven light-shutters.

27. Personal interview with Joseph Donahue, Thomson Consumer Electronics, May 19, 1989.

The multiplexed LCD flat panel is the oldest of the three approaches, and Japanese firms are clear leaders in this area. Four-inch color LCD displays are on the market now in "personal" televisions. These displays have low brightness and contrast, although back-lighting can correct this at the expense of much higher power consumption. Even with backlighting, however, these LCD displays tend to have a narrow viewing angle. The updating of pixel information in multiplexed LCDs is a bit slow, causing some blurring in moving images. The Japanese government has invested around 100 million dollars in projects to develop and improve LCD technology, and each of the major electronics firms has spent additional sums from its own investment funds.

A 14-inch active matrix display developed jointly by IBM and Toshiba uses an array of 1.5 million 4-color liquid crystal pixels, each controlled by a single thin-film transistor which is fabricated along with each pixel, and illuminated from the back by a fluorescent light source. The panel is only 1.5 inches thick and provides 720 by 550 resolution with a very wide viewing angle. BRS Technology, a spinoff from GCA, and a small firm called Alphasil are also working on active matrix technologies.

DARPA (the Defense Advanced Research Projects Agency) has funded a proposal by Raychem and Xerox to develop a thin-film transistor-driven light shutter display for HDTV. Light-shutters (also called light-valves) are a form of liquid crystal display developed originally by General Electric.²⁸ Raychem manufactures light-shutters for low resolution displays using microencapsulation of liquid crystals in plastic. Xerox Corporation will be supplying the TFTs for the Raychem display. Xerox currently manufactures TFTs for FAX machines. Both a flat panel and a projection system will be developed.²⁹

The point of this section is to demonstrate that there are likely to be commercially viable alternatives to CRT and current projection displays for HDTV in the next 5-10

28. Kodak is a major seller of light-shutters in the United States, but the devices it sells are manufactured by Sanyo.

29. Don Clark, "High Tech TV Race Escalates," San Francisco Chronicle, (March 9, 1989), p. C1; "Computer Screens: Down the Tubes," The Economist, (February 25, 1989), p. 78; Interview with Dr. Brian Macknick, Director of Technology Development, Raychem Corporation, in HDTV Newsletter, June/July 1989, p. 11; "IBM, Toshiba Build a Skinny Display Screen," San Francisco Chronicle, March 21, 1989, p. C1; Peter Lewis, "On the Way: Color for Portables," New York Times, April 11, 1989, p. B7; Richard Reimer, "Japanese Vendors Show Functional Color LCDs," Infoworld, May 29, 1989, p. 1; "IBM Works on Flat-Panel Screen," Electronic News, March 27, 1989, p. 20; Joanne Connelly, "DARPA Picks Five Firms for HDTV Contracts," Electronic News, June 19, 1989, p. 6; Gene Smarte and Nicholas M. Baran, "Face to Face," Byte, September 1989, p. 43.

4.0 HDTV SCENARIOS

This part of the report identifies important variables that are necessary in considering future scenarios for the development of an high definition television industry in the United States. These variables are: 1) the **timing** of the adoption of HDTV transmission standards for the United States; 2) the **content** of HDTV transmission standards for the United States, 3) the mix of methods used for delivering HDTV signals to households, 4) the initial and subsequent consumer prices of HDTV receivers, and 5) adaptive strategies pursued by foreign-owned firms in HDTV markets.

4.1 HDTV Standards for the United States

It is now clear that there will be three different transmission standards in the three major consuming regions: North America, Europe, and Japan. Because of the extensive lead of both Japan and Europe in developing DBS (direct broadcast satellite)-based HDTV systems and the incompatibility of those systems with the 140 million NTSC receivers in U.S. households,¹⁷ the United States is forced to consider a third approach.

Even if the United States chooses a transmission standard for HDTV that is incompatible with the Japanese and European approaches, it is unlikely that Japan will abandon Hi-Vision or that Europe will abandon HD-MAC. The only important questions in the standards area center on the timing of the adoption of U.S. standards and the degree of compatibility of those standards with those of Japan and Europe. {Standards issues result from HDTV needs for substantially more transmission bandwidth than the 6 MHz per channel allocated in the NTSC system. -ed.}

4.1.1 The Timing of Adoption of HDTV Transmission Standards

Adoption of HDTV transmission standards can be either fast (i.e., standards adopted by around 1991) or slow. The speed of adoption of standards matters because standards reduce uncertainty for both producers and consumers. The risks associated with uncertainty about standards can slow the rate of investments by producers and

17. National DBS delivery is most compatible with a broadcasting system in which all localities in the nation receive the same signal at any given time. It is easiest to use DBS in countries which do not have different time zones and where local broadcasters are relatively unimportant. DBS delivery requires that all subscribers purchase a small dish antenna and a decoder to receive the DBS signal, in addition to a television receiver.

appearance of large objects.³² But the current usage of computers suggests that small desktop monitors will continue to be the primary form of computer display. Thus, there are reasons to believe that the computer industry, on its own, is unlikely to develop displays appropriate for HDTV.

It has been true historically, however, that the computer industry has benefited from the availability of inexpensive CRT displays. CRT computer displays are inexpensive partly because there is little difference between a CRT for a computer and a CRT for a television. CRTs for computers are produced on the same production lines as CRTs for televisions. Television producers are major suppliers of CRTs for computers.

4.3.3.5 Summary

One of the key problems for the marketplace acceptance of HDTV receivers will be reducing the cost of large displays. The most optimistic scenario for HDTV would include ~~an assumption~~ that a breakthrough in display technology will enable manufacturers to introduce HDTV receivers with large (greater than 40-inch) displays that are relatively compact for less than 1500 dollars retail. A pessimistic scenario would be one in which no breakthrough in displays occurs and initial prices, therefore, are likely to be over 3,000 dollars per unit. If there are no significant improvements in current projection displays, there will have to be a breakthrough in CRT, flat panel, or LCD projection technologies to allow HDTV to become a mass consumer product.

4.3.4 The Role of Manufacturing Technology In Consumer Electronics

Consumer electronics has gone through several generations of change in production technology since the incorporation of transistors in consumer products. The first generation involved the hand placement and wiring of discrete components -- transistors, capacitors, resistors, etc. -- on printed circuit boards. The Japanese innovated simple equipment for inserting components on boards. Initially, this equipment was operated manually by workers. Later, it was replaced by automated insertion equipment. As semiconductor technology moved from discrete devices to integrated circuits and then to large-scale Integrated (LSI) circuits, it became possible to reduce the number of circuit boards in televisions. By 1976, the number of boards needed for the main chassis of Japanese products dropped to one. The reliability of boards increased dramatically and the manhours required to build circuits dropped precipitously.³³

32. Large high-resolution color displays are now being used in automobile design shops to simulate the appearance of new models.

33. The details of this story can be found in Jeffrey A. Hart, "The Consumer Electronics Industry in the United States: Its Decline and Future Revival," op.cit.

As semiconductor technology moved from large-scale to very large-scale integrated (VLSI) circuitry, it became desirable to supplement automated insertion of components on circuit boards with a new assembly method called surface-mount technology (SMT).

Surface-mount technology was invented by Philips but it is increasingly Japanese firms who are the suppliers of SMT equipment worldwide. Instead of positioning integrated circuits with wires or pins over circuit boards, pushing the pins down through holes in the board and soldering them, SMT positions circuits with splayed pins over boards and solders them directly to the surface of the board. This allows the board itself to have a lower profile, thus cutting down on the space required within the equipment for a given amount of circuitry. Combining the space-saving features of VLSI circuits with surface-mount technology allows firms to produce products with unprecedented degrees of compactness. Good examples of such products are the Sony Walkman, Discman, and Watchman, the Motorola Bandit pager, and the Toshiba T1000 laptop computer.

All major producers of consumer electronics equipment have converted production of high-value-added products which require compactness to surface-mount technology. Because SMT reduces manning requirements for assembly lines by approximately a factor of 7, firms which operate assembly plants in high-wage locations are converting to SMT even for products that do not require compactness to reduce their labor costs. For example, almost all producers of add-on boards for personal computers use SMT. However, this production technology is not standing still, and the Japanese producers seem to have an edge in innovation thanks to their large internal demand for SMT equipment. One key question for the future is whether it will be possible to compete with the Japanese in compactness of products and in production costs unless new production technologies are devised.

One important change comes with the growth in the number of pins on integrated circuits with the move to VLSI (and eventually to ULSI). As the pin count increases for integrated circuits it becomes more important and more difficult to accurately position the integrated circuit on a circuit board for bonding. Many firms in the SMT market are working on improved vision systems for accurate placement of integrated circuits on boards. Some U.S. firms, like Adept Technology, are competitive with Japanese firms in this area.

Another likely area for improvement of surface-mount technology is tape automated bonding (TAB). TAB uses a tape in 35mm format, like a movie tape, to convey the chip to a board for mounting. The chip is first bonded to the tape, positioned over a board, and then soldered to the board. Using TAB with SMT increases the speed of

there will be more room for U.S. firms to participate in the market. Even if foreign-owned firms are fast to adapt (this seems highly likely), if they do most of their development work in the United States then there will still be some positive benefits for U.S. competitiveness due to the raising of the skill-base of U.S. technicians and workers and to the likely sourcing of some components from local suppliers.

It has to be admitted from the outset that the U.S. approaches the problem of maximizing its participation in HDTV markets from a position of extreme weakness in consumer systems and of potential strength in electronic components. The most optimistic scenario, therefore, calls for U.S. components firms to cooperate with foreign-owned firms operating extensively in the United States (especially Thomson and Philips but possibly also Sony) while pursuing a policy of long-term efforts to reenter the market with competitive consumer systems products.

4.5 Two Scenarios

Two scenarios provide an appropriate basis for projecting the market for HDTV products -- one is optimistic, the other pessimistic. The optimistic scenario assumes that all the above factors are favorable for rapid take-up of HDTV equipment: i.e., that the setting of U.S. HDTV standards will be early and will favor U.S. producers, that there will be no problem in making the transition away from reliance on local over-the-air broadcasting toward the three broadband media (cable, fiber, and satellite), that initial and subsequent prices of HDTV equipment will be low and therefore attractive to mass consumers, and that foreign-owned firms will not be able to counter the efforts of U.S. firms to win a larger share of consumer electronics markets. The pessimistic scenario assumes that all the above factors are unfavorable. The two scenarios allow us to set upper and lower bounds for projected demand. The optimistic scenario will be used again in Section 7.0 to provide a basis for policy recommendations.

5.0 MARKET PROJECTIONS

This section starts with a review of three previous efforts to project U.S. markets for HDTV products.³⁶ The first is a report for the Department of Commerce performed by Larry Darby of Darby Associates.³⁷ The second is a report for the Electronic Industries Association (EIA) done by Robert R. Nathan Associates.³⁸ The third was done by David Russell of Omnix Systems, Inc., and Robin Whiskin of BIS Mackintosh for the American Electronics Association (AEA).³⁹ Each of these reports uses different methods and assumptions, and accordingly produces different results. Only the report for the AEA provides projections for world markets: the other two are limited to the U.S. market.

The report done for the EIA is the most optimistic of the three; the report done by the AEA is the most pessimistic. Nevertheless, all three reports see the future HDTV market as a large and important market with potentially important benefits for the U.S. economy as a whole.

The major differences among the three reports appear to stem from discrepant assumptions about the timing of the introduction of HDTV equipment, the competition between HDTV and intermediate technologies such as IDTV and EDTV, and the prices of HDTV equipment over time.

The discussion of the three reports is followed by a brief summary of pessimistic projections done subsequently by the Boston Consulting Group for the American

36. A similar review can be found in "The Scope of the High-Definition Television Market and Its Implications for Competitiveness," Staff Working Papers, Congressional Budget Office, July 1989. The author of this study is Philip Webre.

37. Larry F. Darby, Darby Associates, Economic Potential of Advanced Television Products, a report for the National Telecommunications and Information Administration, U.S. Department of Commerce, Washington, D.C., April 7, 1988.

38. Robert R. Nathan Associates, Inc., Industry Research and Analysis Group, Television Manufacturing in the United States: Economic Contributions -- Past, Present, and Future, Chapter IV: High Definition TV's Potential Economic Impact on Television Manufacturing in the United States, prepared for the Electronic Industries Association, Washington, D.C., November 22, 1988.

39. American Electronics Association, Advanced Television Task Force, Economic Impact Team, High Definition Television (HDTV): Economic Analysis of Impact (Santa Clara, CA: November 1988).

Electronics Association and Working Party 5 of the FCC Advisory Committee on Advanced Television Service. The final part of this section of the report considers projections for HDTV sales worldwide.

5.1 Comparison of Three Market Projections for the United States

Two tables summarize the differences in the market projections of the three reports -- Tables 10 and 11. Table 10 focuses on unit volume of sales while Table 11 examines dollar value of retail sales. From Tables 10-11 and Figures 10-11, it should be clear that the Nathan report is the most optimistic of the three in both volume and value projections. While the Darby report approaches the volume estimates of the Nathan report by the year 2002, the Nathan report projects far higher values than the other two. In contrast, the AEA report is the most conservative on both volume and value projections. Only the Darby low estimate of value approaches the AEA value projections.

The AEA report is more pessimistic than the other two primarily because it differentiated between HDTV products and products like improved definition television (IDTV) and extended definition television (EDTV) which would be introduced before HDTV products but which went beyond the standard NTSC sets. Both IDTV and EDTV sets will offer higher performance than NTSC sets without matching the approximate doubling of NTSC horizontal and vertical resolution that HDTV sets will offer. IDTVs were introduced in 1988, mainly by Philips and Sony. They do not alter the 4:3 aspect ratio of NTSC sets. EDTVs, still in development, will probably offer the wider screens of HDTV with its 16:9 aspect ratio. The AEA report factors in the possibility that IDTV and EDTV sales will eat into the prospective sales of HDTV sets for some time after HDTV sets are introduced.

In addition, the three reports differ in their assumptions about the pricing of HDTV receivers (see Table 12). The AEA report envisions the price of HDTV receivers coming down from 4,000 dollars per unit in 1990 to 600 dollars in 2010. The Nathan report sees prices dropping from 2,286 dollars in 1993 to 1,504 dollars in 2003. The AEA and Nathan reports are actually fairly close in their price assumptions. The Darby-Lo price assumption shows HDTV receiver prices wavering around 400 dollars between 1997 and 2008 -- an assumption which seems highly unrealistic. Even more unrealistic is the Darby-Hi price assumption that receiver prices increase from 800 dollars in 1997 to almost 5,000 dollars in 2008.

5.2 More Recent Projections of U.S. Demand

As part of a report on the development of an advanced television (ATV) industry in the United States, the Boston Consulting Group (BCG) projected much slower penetration

of HDTV receivers and VCRs than the EIA, AEA, and Darby reports.⁴⁰ The BCG did not project unit sales or values, but focused only on penetration of households from year of introduction. The method used for this projection was to consider other introductions of consumer electronics products and to isolate factors which made HDTV similar with or dissimilar to those products. BCG decided that because of the high price of HDTV receivers, the slowness with which broadcasters would switch over to HDTV signal delivery, and the lack of HDTV programming initially, the rate of household penetration would be somewhat faster than that for color televisions in the 1950s but slower than that for VCRs in the 1970s (see Figure 12). {The average U.S. household has approximately 2.3 television receivers. -ed.}

Working Party 5 (WP-5) of the FCC Advisory Committee on Advanced Television Service also projected penetration rates for HDTV receivers. Like the BCG, WP-5 was more pessimistic than EIA, AEA and Darby about these rates. WP-5 assumed that HDTV signals would be downward compatible with NTSC receivers and that three years after the introduction of receivers 15 percent of the television broadcast stations in the largest one-hundred metropolitan regions would be delivering HDTV signals. WP-5 also assumed that the largest cable programming networks would convert quickly to HDTV signal delivery. In addition, WP-5 assumed that HDTV receiver prices would be comparable to the prices of color televisions after introduction in constant dollars, and that the percentage of consumers who strongly preferred HDTV to NTSC would be somewhat less than that of those who preferred color to black and white. WP-5's projections are displayed in Figure 13. They show HDTV receivers penetrating only 30 percent of U.S. households by 2010, as compared with nearly 100 percent in the Darby study and over 50 percent in the AEA study.⁴¹

5.3 World Market Projections

The AEA report is the only one of the three reports which includes world market projections. Table 13 reproduces the value projections for the world HDTV receiver market. The AEA report assumes that HDTV receivers will be introduced first in Japanese markets, and roughly simultaneously thereafter in other markets. That is why Japanese sales peak before those of other regions. The cumulative sales of HDTV receivers between 1990 and 2010 are projected to be over 170 billion dollars.

40. The text of the report is contained in the testimony of Pat Hill Hubbard, Vice President, American Electronics Association, before the Senate Committee on Commerce, Science, and Transportation, May 89, 1989.

41. "WP-5 Projection of ATV Receiver Penetration," memo to Laurence Thorpe, Chairman, WP-3, from Michael Tyler, Chairman, WP-5, FCC Advisory Committee on Advanced Television Service, Document 245/M-11, no date. This document was produced in the summer of 1989.

There is a rapid rise in global annual sales to a peak of 17 billion dollars in 2004 followed by a temporary market lull, presumably induced by market saturation in the three major industrial regions, and then a revival beginning in 2009. Given the conservatism of AEA projections for the U.S. market, one can assume that these estimates for the world market are also conservative.

The Ministry of Posts and Telecommunications (MPT) of Japan projects an increase in the size of HDTV-related sales (which includes receivers, VCRs, video tapes, and other items) from 0.2 trillion yen in 1990 to 3.4 trillion in 2000. The total sales for this period will be 14.5 trillion yen, of which 97.5 percent will be in consumer and industrial television sets (see Figure 14).⁴² HDTV receivers will be in 10-15 percent of households and other sites by 1995. Penetration will reach 30 percent by the year 2000.⁴³

BIS Mackintosh has forecast worldwide HDTV sales for the 1990-2010 period in millions of units (see Figure 15). These forecasts are for HDTV receivers only and do not include sales of EDTV units or wide-screen MAC receivers. The Mackintosh projections show Japanese sales ramping up faster than those in Europe and the United States, but peaking lower and earlier, at around 5 million units in 2005. In 2010, European sales reach 8 million units, U.S. sales exceed 10 million units, and rest of world (ROW) sales pass 6 million units. Thus, global sales of HDTV receivers are projected to be around 30 million units in 2010.⁴⁴

5.4 Putting the Projections In Perspective

The various reports discussed in this section provide some empirical basis for assessing the importance of future markets for HDTV receivers. The total HDTV market will include VCRs, cameras, and other video peripherals, of course, and there may be some important linkages between HDTV displays and markets for computers and telecommunications equipment. As we will see in the next section, it may not be entirely appropriate to think of HDTV equipment as stand-alone devices mainly used for entertainment. HDTV receivers and displays may become part of relatively more

42. Lawrence E. Tannas, Jr., "HDTV and HDTV Displays," paper presented at a meeting of the HDTV Workshop of the Japanese Technology Evaluation Center (JTEC), Washington, D.C., July 26, 1989, p. 3.

43. Japan Electronics Almanac 1989 (Tokyo: Dempa, 1989), p. 159.

44. These figures were provided to me by Robin Whiskin of BIS Mackintosh. It should be noted that Robin Whiskin also provided the raw data for the AEA forecasts of HDTV demand.

integrated home information and automation systems. Nevertheless, the projections discussed here all agree that HDTV markets will be substantial by the year 2010 and that there should be significant opportunities for U.S. participation in them.

6.0 RESOURCE LINKAGES

This section deals with the technological linkages across industries, focusing especially on the linkages within electronics. It examines specifically the importance of the electronics complex within the U.S. economy and for the rest of manufacturing. In addition, it examines the relationships between consumer electronics and the electronics complex.

6.1 Electronics as a Strategic Industry for U.S. Competitiveness

From a national competitiveness perspective, the critical node of the electronics sector is the microelectronics or semiconductor industry. Semiconductors are at the heart of electronics products ranging from computers, telecommunications systems, and industrial robots to VCRs, video games and state-of-the-art television receivers. More fundamentally, semiconductors are a major source of innovations in products and processes throughout the economy.

The spillover effects of the microelectronics revolution on the rest of the economy are best understood by distinguishing between two categories of effects: **linkage impacts** and **technological spillovers**.⁴⁵ Linkage impacts are those that generate increasing positive benefits to economic activities tied to chip production, for example, the production and use of products, such as computers and sophisticated telecommunications equipment that incorporate chips. Technological spillovers are pervasive, benefit-creating impacts on scientific and technological activities more loosely associated with chip development and production, for example, research and development in physics or superconductivity.

6.1.1 Linkage Impacts

Linkage impacts, sustained economic benefits in linked activities, arise because chip production generates a cycle in which increased investment in research and development and capacity leads to increasing chip performance at decreasing cost. The improved price-performance characteristics in turn deliver improved price-performance in downstream products like computers, and also generate new markets as in antiskid braking systems. The applications generate broad societal returns. As downstream markets expand, substantially increased demand for chips is generated. Increased user demand occasions expanding investment in chip development and production which leads to another round of improved

45. The following discussion is from Michael Borrus, Competing for Control: America's Stake in Microelectronics (Cambridge, MA: Ballinger, 1988).

price-performance. The cycle is repeated. Such has been the history of the microelectronics industry for over three decades.

6.1.2 Technological Spillovers

Although somewhat imprecise by contrast to linkage impacts, technological spillovers generally result from the interdependence that characterizes precursor and complementary technological activities. This is most obvious in the relationship between chips and the systems that incorporate them. Increasingly, the chips embody the systems functions and performance characteristics of the products that incorporate them: advanced chips are systems and innovation in systems occurs at the level of the chip. This is the most precise type of technological spillover but there are other broader spillovers as well.

Advances in chip technology depend upon and contribute to continued technological innovation in physics, chemistry and materials sciences. For example, it is no coincidence that recent advances in superconducting materials originated partly at IBM Research, AT&T, Bell Laboratories, and Bellcore, where the search for superfast microelectronic switching devices for computer and telecommunications applications motivated experimentation with superconductivity. The gains from superconductivity will not be confined to chips but will pervasively influence activities ranging from electricity generation to high-speed transportation.

6.1.3 Microelectronics Drives Product and Process Innovation

As a result of both linkage effects and technological spillovers, microelectronics has been a driver of both product and process innovation throughout the economy. Microelectronics-based technologies are already automating both primary commodity and goods production and transforming the activities that make up the service industry. Global competition in a variety of both traditional industries, such as textiles and steel, and high-technology industries, such as aircraft is increasingly based on microelectronic-driven innovations.

6.1.4 Employment and Revenue Impact of Electronics

In addition to their effects on innovation and competitiveness in a wide variety of industries, the microelectronics industry and the electronics sector, more broadly defined, are important to national competitiveness in more direct ways. Between 1965 and 1985, the global output of the electronics complex grew by over 13 percent per annum in real terms, and by 1985 it equalled the global output of the automobile industry and surpassed the global output of the steel industry. In 1987, U.S. sales of electronics products exceeded more than one-quarter of total industries' shipments and have been growing at over 5 percent annually. Electronics in total employs more than a million and one-half Americans, many of them highly skilled. The wage of the average worker in the electronics industries is higher than the average wage of

workers of similar skill, education, experience, and personal characteristics, such as age, sex and race, in many other manufacturing activities and in most service activities.⁴⁶

6.1.5 Linkages with Other Sectors of the Economy

The electronics sector is tightly linked to many other portions of the U.S. economy. Not only do the nation's defense industries depend on electronic technologies, but both manufacturing and service industries -- ranging from the production of numerically controlled machine tools to banking and insurance -- use electronic products both directly and indirectly. These products -- which range from CB radios to satellite-based communications systems, carbon resistors to vastly powerful computers -- are probably distributed more widely through the rest of the U.S. economy than the output of any other industry.⁴⁷ Because many electronics products serve as inputs in other sectors of the economy and because they are produced under conditions of increasing returns or declining costs, due to the significant learning curve economies realized in their production, the electronics sector gives rise to what economists call "linkage externalities" -- increasing private returns in the electronics industry result in increasing social returns in downstream user industries.

6.1.6 Role of Electronics In Trade

Finally, as the global electronics industry has grown, it has become an increasingly important determinant of national trade flows and national trade balances. The U.S. trade position in electronics deteriorated between 1980 and 1987, although measures of the extent of the decline vary depending on how broadly electronics is defined (see Table 8 and Figure 4).⁴⁸ All of the estimates indicate that the decline was broad-based, ranging from consumer electronics and components to office and

46. This conclusion is based on calculations in Williams Dickens and Kevin Lang, "Why It Matters What We Trade," in Laura D'Andrea Tyson, William Dickens, and John Zysman, eds., The Dynamics of Trade and Employment (Cambridge, MA: Ballinger, 1988).

47. Office of Technology Assessment, International Competitiveness in Electronics (Washington, D.C.: USGPO, November 1983).

48. It is important to emphasize that the electronics trade balance is heavily influenced by the decisions of U.S. multinationals. Some estimates indicate that as much as a third of the electronics imports from individual East Asian countries come from U.S.-owned operations.

computing equipment and sophisticated telecommunications equipment. Notably, the electronics trade deficit continued to increase despite the dollar's decline. Even with further declines in the dollar's value, the U.S. will continue to run a significant deficit in many electronic products. This is true for many consumer electronics items.

To illustrate, about 13.3 million VCRs were sold in the U.S. in 1987. Only 230,000 were made in the U.S. (assembled from imported parts), resulting in a total import bill of over \$3 billion. Although by 1989, nearly 900,000 VCRs are expected to be made in the U.S., they will represent approximately 7 percent of estimated sales, and will likely rely heavily on imported components, implying a continued large deficit in this item for the foreseeable future.⁴⁹

Another example of this was the recent growth in demand for hand-held LCD televisions. In 1984, only 32,000 LCD televisions were sold in the U.S. By 1986, 771,000 LCD televisions were sold in the U.S., all of them imported from Japan. In 1986, Japanese firms produced over 1.7 million LCD sets. They had been able to descend their learning curves for production of LCD displays so quickly that it was impossible for their foreign competitors to enter the market for LCD televisions.⁵⁰

A third example is compact disk (CD) players. The market for CD players has grown very rapidly since the introduction of these devices by Sony in 1982. After the introduction of the portable CD player called "Disc Man" by Sony in 1985, the average price of nonportable CD players dipped below 200 dollars per unit and sales took off. In 1986, CD unit sales first exceeded those of LP record players. By 1987, Japanese firms had sold 45 million units worldwide. Only Philips and the Japanese firms were able to manufacture the gallium arsenide laser diodes -- which are vital to reading the information recorded on compact discs -- at world competitive prices. In addition, Japanese firms rapidly reduced the core chip count in CD players from 3 to 1 by using VLSI circuit designs with smaller line widths.⁵¹

6.1.7 U.S. Competitiveness In Electronics Is Declining

49. Allen Lenz, "Slimming the U.S. Trade and Current Account Deficits," The AMEX Bank Review, Special Papers, No. 16 (October 1988).

50. U.S. International Trade Commission, Liquid Crystal Display Television Receivers from Japan, USITC Publication 2042, Washington, D.C., December 1987.

51. Presentation by Heitaro Nakajima, Executive Technology Adviser, Sony Corporation, on "The Conception and Evolution of Digital Audio," February 17, 1989, University of California, Berkeley; phone interviews with representatives of various CD producing firms.

World production shares in electronics also indicate a drop in U.S. competitiveness relative to other regions. According to an analysis of data collected by the Electronic Industries Association of Japan, the U.S. production share of electronics dropped from 50.4 percent in 1984 to 39.7 percent in 1987. During the same period, Japan's share rose from 21.3 to 27.1 percent. The same trend was observed in a different study, with slightly different numbers, done by the European Electronics Industry Council.⁵²

World production shares in semiconductors also indicate a drop in U.S. competitiveness in the last decade, particularly relative to Japan. Figures from Dataquest indicate that Japan produced slightly more than 50 percent of world production in 1988 while the U.S. produced around 37 percent. In 1978, the U.S. accounted for 55 percent and Japan less than 30 percent of world production.⁵³

6.2 The Linkages Between Consumer Electronics and the Electronics Complex

There are three important forms of linkage between the consumer electronics industry and the rest of the electronics complex. They are:

- * upstream effects
- * downstream effects
- * manufacturing effects

6.2.1 Upstream Effects

Upstream effects derive mainly from the role of the consumer electronics production as a source of demand for inputs, and in particular for semiconductor components. The consumer electronics industry in the United States first contracted and then shifted from domestic to predominantly foreign ownership. The ability of U.S.-based semiconductor firms to service markets for consumer-related semiconductors virtually disappeared.⁵⁴ By the mid 1980s, only 6 percent of the production of semiconductors

52. Lawrence M. Fisher, "U.S. Share Declines in Electronics," New York Times, (January 5, 1989), p. C1.

53. "Preliminary 1988 Worldwide Semiconductor Market Shares: Japanese Gain Share: Memories and Micros Dominate Market," Dataquest Newsletter, January 1989, pp. 1 and 3.

54. It should be noted that the decision of U.S. semiconductor firms to stop building chips for consumer electronics came at the beginning of the massive growth in imports of consumer products and much earlier than the acquisition of major U.S. consumer

in the U.S. went to consumer applications, whereas in Japan, the corresponding figure was 40 percent. In dollar terms, this meant that Japan was producing 7.2 billion in consumer chips in 1987 while the U.S. produced only 0.9 billion. The corresponding figure for Europe was around 4 billion.⁵⁵

There is an honest dispute about how this occurred. Some U.S. firms claim that foreign-owned consumer electronics firms had preferential supply arrangements which excluded them from the market. The more vertically-integrated foreign electronics firms often sourced their semiconductors from their internal semiconductor divisions. In all the major industrialized regions, there is a preference for working with regional suppliers of components wherever possible. The Japanese consumer industry, as represented by the Electronic Industries Association of Japan, claims that U.S. firms were unable to produce the necessary products, or to deliver them on time, or to match the quality/reliability of other (particularly Japanese) producers. The U.S. semiconductor firms accuse the Japanese of preferentially sourcing from Japanese semiconductor producers. Both of these claims are true. Of key importance for many U.S. firms was the fact that the consumer chip business was less profitable, because it involved standard devices in which markets were highly competitive, than business for industrial or defense applications.

The abandonment of consumer chip production made it difficult for U.S. semiconductor firms to produce certain kinds of generic circuitry at commercial volumes: e.g., charge-coupled devices (CCD), composite metallic oxide on silicon (CMOS) circuitry,⁵⁶ and liquid crystal displays (LCDs). Since digital VCRs use random access memory (RAM) devices for frame storage, the lack of a U.S.-based VCR industry had a marginally negative effect on demand for RAMs in the United States.

6.2.2 Downstream Effects

Downstream effects refer to the impact of consumer electronics on industries downstream from the semiconductor industry. The lack of commercially-priced CCD chips helped to keep U.S. firms out of the video camera markets. The Japanese edge in CMOS circuitry helped Japanese firms to establish a strong presence in laptop computer markets. Japanese strengths in LCD helped to give them an edge in the

firms by foreign firms.

55. Testimony by Jeffrey A. Hart before the Subcommittee on Telecommunications of the House Committee on Energy and Commerce, September 7, 1988, p. 8.

56. It should be noted that several U.S. semiconductor firms, including Harris and National Semiconductors, remain highly competitive in CMOS circuitry.

emerging markets for laptop computers and hand-held televisions. It is widely recognized that Japanese firms are ahead of all their competitors in the commercial development of CCD, CMOS, and LCD technologies.

6.2.3 Manufacturing Effects

Manufacturing effects involve the loss of strength in generic manufacturing skills and technologies associated with the reduced role of U.S. firms in the consumer electronics industry. While a number of U.S. firms were able to match their international competitors in the adoption of advanced manufacturing techniques, such as automated insertion and surface-mount technologies, the majority failed to do this rapidly enough to meet the competition. These technologies are important not just for consumer electronics but for many other kinds of high-volume production. The decline of the U.S. consumer electronics industry, therefore, meant a narrowing of the manufacturing skill base of the U.S. economy.

6.2.4 Upstream, Downstream, and Manufacturing Effects Will Be Greater with the Advent of HDTV

There are reasons to believe that upstream, downstream, and manufacturing effects will be even greater in the next two decades than they were in the past. Because of the need to process more information about video images, HDTV circuitry will be much more complex than NTSC circuitry. HDTV circuitry needs will contribute to advancing technology in some important areas, such as digital signal and image processing, and parallel processing. HDTV receivers will require random access memories for frame storage (NTSC receivers do not have frame stores {excepting recent IDTV units. - ed.}). In addition, competition in the HDTV business will create large incentives for the development of large displays.

The downstream spillover effects of HDTV technology will be significant in the computer, defense electronics, and telecommunications industries. The problems of image and digital signal processing that have to be solved for HDTV receivers also have to be solved for fast displays of color images on advanced computer workstations. The production of large, high-resolution displays for HDTV equipment will allow some firms to produce cheaper and more competitive displays for computers and workstations.

There is an important mutually reinforcing relationships between advances in HDTV and network (telecommunications) technology. The networking of advanced computer workstations creates network architecture design problems similar to those posed by the use of HDTV receivers as interactive terminals. Interactive video and interactive 3-D color CAD/CAM are both more demanding than existing interactive character and

graphics networking.⁵⁷ If you can solve one problem, then you have contributed to the solution of the other. The unanswered question in this equation is how much demand there will be for "interactive" (two-way) as opposed to "passive" (one-way) television.

More important than the technological linkages between HDTV and telecommunications are the likely linkages between the two that arise with the building of a new national telecommunications infrastructure based on optical fibers. HDTV signals will be delivered to the home long before the fiber network is operational. Nevertheless, the sooner HDTV home delivery begins the sooner there will be demand for transmitting HDTV signals via fiber (because of the greater fiber optic bandwidth and the opportunity for reducing transmission noise with broadband digital signals). By the same token, the faster high quality fiber delivery to the home is in place, the easier it will be to convince consumers to make the switch from NTSC, or interim products, to HDTV. Fiber home delivery can be speeded by adopting a policy of encouraging the local and regional telephone companies to compete with the cable operators in connecting homes to fiber networks.⁵⁸

The greater is U.S. participation in HDTV consumer markets, therefore, the greater will be the upstream, downstream and manufacturing benefits for the rest of the U.S. economy. Thus, policy measures should be aimed at maximizing U.S. participation. Because European firms already possess such an important stake in U.S. research and development and manufacturing of consumer electronics, they have to be included in efforts to promote the HDTV industry in the short and medium term.⁵⁹

57. Workstation firms are now introducing NTSC video image processing in the high-end of their product lines.

58. Current estimates suggest that installing a 600 megabit per second fiber optical link from the trunk to the average home will cost around 2,000 dollars. Telephone companies and cable operators are beginning to install fiber instead of wire cables because fiber costs, especially maintenance costs, have become much more competitive.

59. Joseph Donahue, of Thomson Consumer Electronics in Indianapolis, estimates that the annual R&D expenditures of Thomson, Zenith, and Philips in the United States are around 150 million dollars per year.

7.0 RECOMMENDATIONS

This section starts with a brief argument about the importance of U.S. reentry into consumer electronics markets and the reasons for selecting HDTV as the main vehicle for that reentry. It then summarizes the obstacles that have to be overcome for a reentry strategy to succeed. A set of general principles for a U.S. reentry strategy are provided along with some specific policy recommendations to implement them. The section concludes with some recommendations about economy-wide measures that can be taken to reinforce the narrower reentry strategy.

7.1 The Importance of U.S. Reentry Into Consumer Electronics

Reentry in consumer electronics is vital for two main reasons. First, consumer electronics products drive the creation of high-volume, low-cost production of leading-edge components. Such components have broad application throughout the entire electronics industry. Second, the mass production associated with consumer electronics can be used as a proving ground for innovations in electronics materials, equipment and manufacturing techniques.

7.1.1 Why Participation in HDTV Markets Will Promote Innovation in Electronic Components

Until relatively recently, U.S. participation in the consumer electronics industry did not appear to be crucial to its economic strength. U.S. firms have had a comparative advantage in other, more capital- and knowledge-intensive industries. In particular, U.S. firms created a strong technological base for themselves in digital technology. They tended to restrict their research and development investments to computer, telecommunications, and military electronics, where the returns on investment were more secure than in consumer electronics. Poor enforcement of trade laws combined with unwise strategies on the part of traditional consumer electronics manufacturers translated into a nearly universal exit from consumer systems markets. A small number of U.S. firms held on as suppliers of advanced circuitry to Japanese consumer producers, but the production of consumer circuitry generally followed the production of systems in leaving the country. This was probably not so important with the NTSC television systems of the mid 1970s and earlier, as the types of circuitry required were highly standardized and mostly analog devices, with few applications outside of consumer electronics.

With the introduction of VCRs, video cameras, LCD televisions, and CD players, a new era of consumer technology came into being. The electronic circuitry in these systems was more complex and increasingly utilized digital techniques, to supplement the traditional analog approaches used in television and radio. European firms, in particular, were fast to introduce digital circuitry into traditional consumer systems as a competitive strategy for differentiating products. Japanese firms, in contrast, focused

on building specialized analog large-scale integrated circuits for televisions and in innovating new types of components, both electronic and mechanical, for VCRs, LCD televisions, and CD players. The Japanese (and Philips) were successful in securing strong competitive positions in the higher-value-added products that resulted.

With the introduction of HDTV products, it will become even more necessary for the U.S. firms to regain a position in consumer electronics markets in order to safeguard U.S. competitiveness and national security interests. It is no longer the case that consumer circuitry bears no relationship to the circuitry that is needed for computers and telecommunications equipment. HDTV product development will push out the technological frontier in such important areas as analog/digital converters, digital signal processors, video image processors, decoders/encoders, and broadband switching circuitry.

7.1.2 Why Participation In HDTV Markets Will Help to Promote Innovation In Manufacturing Technology

Because consumer products tend to have shorter and shorter life cycles and because of the need to compete with producers in low-wage countries, flexible automation is crucial for the economic survival consumer electronics systems firms in high-wage regions. Japanese electronics firms have been far in front of U.S. firms in the introduction and diffusion of automated insertion equipment and surface mount technologies for assembling printed circuit boards. They have been much more ambitious than U.S. firms in introducing reprogrammable robots and computer-integrated manufacturing in their consumer electronics operations. The Japanese are ahead in the automation of bonding and packaging in the assembly of semiconductors as well. U.S. non-participation in consumer electronics production has meant that U.S. firms have not had to wrestle with the exigencies of flexible high-volume production.

If the United States is serious about securing a bigger share of world consumer electronics markets, then it must adopt a strategy to neutralize the substantial Japanese advantages in components and systems manufacturing technologies.

7.2 What are the Difficulties to be Overcome In Reentry?

To say that U.S. reentry into consumer electronics will be difficult is an understatement at best.

7.2.1 There Is Only One Major U.S. Firm In Consumer Systems

Zenith is the only major U.S.-owned producer of televisions. There are other U.S. firms which produce consumer items, especially if one includes personal computers

and peripherals as belonging in this category. For example, Motorola produces cellular phones and telephone pagers, Hewlett-Packard makes printers and terminals, Texas Instruments manufactures calculators, and IBM makes printers and typewriters. A growing number of small firms are supplying NTSC video-imaging boards for use in personal computers. But Zenith, because of its role in television, would have to be part of any U.S. strategy to increase its participation in consumer electronics via HDTV.

Zenith is in weak shape, financially and technologically, to be an adequate base for the building of a U.S. HDTV reentry strategy. Zenith's consumer electronics operations have been unprofitable since 1985. Only its diversification into a profitable personal computer business saved it from bankruptcy or acquisition. In the last two years, rumors have abounded about imminent takeovers by European or Asian firms. Wall Street investors have put strong pressures on Zenith management to sell off the consumer business in order to improve the overall profitability of the firm. {Zenith has recently sold its personal computer business to Bull of France and will now concentrate on the consumer business. -ed.} Because of the low profits in televisions, Zenith has been unable to invest sufficient amounts in research and development to keep up with its international competitors in developing HDTV technologies. One of the reasons why Zenith approached DARPA recently with a proposal for DOD funding for the upscaling of its FTM (flat tension mask) monitor was the lack of internal funds to do this on its own.

7.2.2 U.S. Consumer Circuitry Production Is Weak

Because of the dominance of European and Asian firms in consumer systems and because of the higher profits available in other areas of electronics, U.S. semiconductor firms are weak in the design and production of consumer circuitry. Even Zenith does not source its components from U.S. firms, but rather primarily from ITT (Europe) and Matsushita. Similarly, both Thomson and Philips source consumer chips primarily from European and Japanese semiconductor firms. Thomson-Europe sources primarily from ITT (Europe) and Oki. Thomson-U.S. sources also from Motorola, National Semiconductor, and Harris (which purchased the semiconductor division of RCA).

7.2.3 The U.S. Market Is Open, The Others Are Not

Consumer systems market in this country are already crowded. There are already six Japanese firms producing televisions, two European, one U.S. and two Korean firms. By contrast, only the Japanese and Korean firms have access to the Japanese market, and access to the European market is similarly restricted.

7.2.4 U.S. Electronics Firms Are Less Vertically Integrated

The structure of the U.S. electronics industry is more fragmented than that of either Japan or Europe. This means that several layers of U.S. firms must cooperate to effectively reenter the market, especially given the inevitability of continued competition from foreign manufacturers. It may be necessary to forge alliances among firms in a number of industries, including semiconductors, telecommunications, computers and automotive electronics. (Although these industries are still relatively disparate, they are moving in converging directions with regard to components and manufacturing technologies.)

7.3 The U.S. Can Build from Strength

Despite the obstacles, reentry is not impossible. U.S. firms continue to show strengths in some areas of electronics, especially computers, automotive electronics and telecommunications. As discussed above, each of these industries utilizes technologies that are increasingly related to the next generation of consumer systems. While cooperation and utilization of existing strengths will be necessary for reentry into consumer electronics, it may not be sufficient. Successful reentry will also require government policies to overcome existing industrial weaknesses (see Section 7.4 below).

However, it is important to recognize that any attempt at reentry will probably be unprofitable, at least in the short run. This alone will deter some American manufacturers from expending the necessary resources to begin producing consumer systems. Because of the U.S. weakness in consumer systems, it will be necessary to establish cooperative arrangements with foreign-owned firms operating in the United States in the short to medium term, so as to establish a technological and manufacturing base for more autonomous development efforts later.

The most likely partnerships will be between Zenith and the two European systems firms, Thomson and Philips, and U.S. semiconductor producers. In certain very specific areas, such as LCDs, it may be prudent for U.S. firms to cooperate with the weaker Japanese firms. The main problem with U.S.-Japanese partnerships in consumer electronics is that the Japanese firms, for the most part, do not need help from the U.S. firms. In addition, Japanese firms have been unwilling, with the possible exception of Sony, to invest in research and development in the United States. In the long term, there have to be new entries by U.S. firms into consumer systems markets to make U.S. reentry into consumer electronics self-sustaining.

7.3.1 Is HDTV the Right Vehicle for Reentry Into Consumer Markets?

Reentry into consumer electronics markets will require a specific vehicle, that is, a decision to focus on a particular consumer product. HDTV should be that vehicle. Because HDTV incorporates sophisticated integrated circuits and memory capacity, production of HDTV receivers would provide a significant source of demand for those components. Moreover, the rapid diffusion of HDTV is likely to require changes in the

way that video signals are transmitted to homes. In Section 4.2 above, it was argued that the most effective ways of delivering HDTV signals to households will be via optical fiber and satellites. The use of broadband media for the delivery of HDTV signals may speed the building a national broadband telecommunications network which could be an important infrastructural underpinning for the overall growth and competitiveness of the U.S. economy.

7.4 General Guidelines for the U.S. Response

Given the enormous potential of HDTV technology, as well as obstacles facing potential producers, what type of strategy should the United States adopt if HDTV is to help the U.S. industry regain its competitiveness in consumer electronics? In formulating the specifics of such a strategy, policy-makers should keep six general guidelines in mind.

First, business strategy should determine the choice of technologies to support, rather than vice versa. This is a fundamental point if U.S. firms are to establish a self-sustaining presence in those parts of the consumer electronics business that contribute to industrial and military strength. Anything else will require enduring subsidies and will likely fail to keep pace with foreign technical advances. Thus, self-sustaining presence can only be built through successful commercial strategies -- not through defense-led technology development.

Second, the business problem must be defined as the need for U.S. industry to capture a significant share of HDTV and related markets. The strategy adopted must identify the policies that are necessary to achieve this end, including the appropriate roles for government and industry. Moreover, several terms must be carefully defined within the context of a coherent strategy -- including "HDTV-related markets," "U.S. industry," and "significant share."

Third, the strategy adopted must identify key industrial and governmental players. Moreover, it is important to identify appropriate sources of funding and the organizational forms that will be necessary to achieve market and technology goals. Specific policies must be adopted in a number of key categories, including research and development, trade, antitrust, standards, regulation, fiscal and monetary policy, education and training, and procurement.

Fourth, a strategy is necessary to compensate for advantages that foreign firms derive from their more highly integrated firms and less competitive regional markets. There are a number of ways to do this. For example, a consortium could be formed around a U.S.-owned consumer systems champion for development of new HDTV technologies; since Zenith is the only major U.S.-owned systems firm it would become the "consumer champion" by default.

Fifth, U.S. firms could enter into ventures with foreign firms that are strong in consumer systems but weak in components production (for example, European or Korean firms).

While the fourth and fifth options are both viable in the short run, neither will be a long-term, self-sustaining option in consumer markets unless three other options are also chosen: **sixth**, the formation of a consortium for the joint production of receivers; **seventh**, the entry of large companies like IBM and AT&T into HDTV product markets; and **eighth**, the entry of small start-up firms into specialized niches in the HDTV market with "open architecture" systems.

Ninth, any U.S. strategy for a self-sustaining presence in consumer markets will require the fortification of intellectual infrastructure through education and research. Universities can play a vital role in this effort. Similarly, there must be efforts to develop skills at the secondary school level -- for example, through initiatives in vocational education.

7.5 Specific Policy Options and Recommendations

Keeping the above general principles in mind, let us turn to a number of specific policy options that are designed to promote a self-sustaining U.S. presence in consumer electronics via HDTV reentry. (The options presented in this section assume that it is not necessary to adopt changes in policies that affect the economy as a whole. That assumption will be reexamined in the next section.)

All policy interventions carry with them some risk of making things worse. For example, there have been few examples of successful military funding of commercial technologies in recent years. A frequently cited example of ill-conceived efforts is the VHSIC (Very High-Speed Integrated Circuit) program. While Sematech provides a precedent for joint public and private funding of consortia, it may not prove to be a useful model for what is to be done in consumer electronics.

Consequently, the following proposals are presented in a deliberately provocative manner in order to generate a serious discussion of public policy options -- those that provide something beyond incremental decision making.

7.5.1 Phase Out Over-the-Air Broadcasting in Ten Yearst

One ambitious long term proposal would have the Federal Communications Commission mandating that all over-the-air broadcasting be phased out in a ten-year period. At the end of that period, all VHF and UHF spectrum would be reallocated for

cellular radios -- perhaps with the possibility of allocating cellular broadband for portable video applications. This would have the effect of speeding both the diffusion of HDTV equipment and the construction of a national fiber network.

7.5.2 Encourage Cable and Telephone Companies to Compete In Connecting Homes to a National Fiber Network

An equally ambitious long term option would be for Congress, the FCC and other agencies to encourage the Regional Bell Operating Companies (RBOCs) and the cable television operators (or their future counterparts) to provide each household with a 600 Megabit/second optical fiber link to the national fiber network. Households would be permitted to add other equipment to the fiber connectors, including more sophisticated HDTV devices. The cost of paying for the link to households (approximately \$150 billion) could be shared between advertisers, video service providers, telecommunications service providers and consumers.⁶⁰ Government policy would encourage RBOCs and cable operators to compete in providing video and telecommunications services to households.

7.5.3 Fund National Research and Development Programs for HDTV Technologies

A more focused long-term proposal would establish priorities for public and private funding of research and development consortia. The four areas that should receive top priority are displays, digital signal and video image processing circuitry, broadband switching, and consumer electronic manufacturing technology. While the current DARPA focus on displays and display circuitry is important, it runs the danger becoming blindsided on the telecommunications aspects of HDTV and manufacturing. The implications for consumer electronics should be kept firmly in mind.

DARPA (the Defense Advanced Research Projects Agency) issued a Broad Area Announcement (BAA) for a program to fund research in displays and display circuitry on December 23, 1988. In the BAA, it was suggested that around 30 million dollars would be available -- about half of which would be allocated to displays and half to display circuitry. The closing date for proposals under the BAA was February 13, 1989. DARPA officials suggested that they might use the proposals they receive to initiate a second round of proposals in which first-round proposers are asked to form teams with others for funding of projects. They also suggested that they were open to proposals from foreign-owned firms with major research and development and manufacturing presence in the United States.

DARPA received 87 proposals for displays and display circuitry. DARPA's Deputy Director for Research, Craig Fields, testified on March 8, 1989, before the Subcommittee on Telecommunications and Finance of the House Committee on Energy

60. As always, the bill for doing this will be paid ultimately by the consumer.

and Commerce, that he was extremely pleased with the number and quality of proposals. Notable among them was a proposal from Zenith with AT&T as a subcontractor for the development of HDTV circuitry. Zenith and AT&T announced that they would pursue this joint effort whether or not DARPA decided to fund it.⁶¹

In addition, Sony Corporation submitted a proposal for developing MUSE-based displays and image-processing technologies. There was some skepticism about the seriousness of this proposal given contradictory statements from Sony spokesmen about where the research would be conducted. It is possible that Sony submitted the proposal to test the resolve of DARPA and the U.S. government to permit only those foreign firms to participate in publicly funded consortia who build major research and development and production capabilities inside the United States.⁶²

The DARPA effort is a focused one and does not involve a great deal of money. It may not lead to a consortium, per se, but the contacts developed by participants in that effort have already helped to create an impetus for further cooperative ventures among firms operating in the U.S. The same can be said of the efforts of the AEA group of 36 firms who agreed to fund (at between 2,500 and 5,000 dollars each) the writing of a business plan for an HDTV consortium. The Boston Consulting Group was selected to help write the business plan.⁶³

The idea of forming a consortium for electronics technology funded jointly by government and industry was discussed recently under the auspices of the IEEE-USA. A proposal for a private consortium called the Technology Corporation for America (TCA) was initially discussed in the so-called Verity Committee, a group of CEOs from U.S. firms assembled by Secretary of Commerce William Verity in November 1988. It was taken a bit further in a meeting convened at MIT by Professor David Staelin on February 14-5, 1989. Two industries were the particular focus of those discussions: HDTV and machine tools. Four working groups were formed to discuss: 1) dual-use technologies, 2) standards, 3) institutional structures, and 4) legal and political issues. The meeting in mid-February concluded with an agreement to focus further discussions on generic technologies rather than on consortia specifically aimed at HDTV reentry or recovery in machine tools.⁶⁴ But this forum is just another indication of the high

61. Peter Waldman, "Zenith and AT&T Team Up to Build High Definition TV," Wall Street Journal, (March 1, 1989), p. 1.

62. Calvin Sims, "Sony Seeks TV Grant from U.S.," New York Times, (March 3, 1989), p. C1.

63. Telephone conversation with Pat Hubbard, AEA, March 16, 1989.

64. Telephone conversation with David Staelin, February 11, 1989.

interest of both policy makers and industrialists in cooperative efforts to advance underlying technologies.

7.5.4 Create a Consumer Electronics Capital Corporation

One of the most interesting proposals put forward in recent months was by Jack Tramiel of Atari Corporation to a small group of CEOs convened by Charles Sporck of National Semiconductor. This proposal calls for a Consumer Electronics Capital (CEC) Corporation. The CEC would obtain financing on the open market and make loans to domestic consumer electronics enterprises with loan guarantees from the U.S. Export-Import Bank. The guarantees on loans would allow the loans to be long-term, and contributions from public agencies could provide a subsidy element to make the loans low-interest as well. This would reduce the risk for U.S. firms reentering consumer electronics markets and allow them the luxury of a longer time horizon for their investments.⁶⁵

7.5.5 Fund Development of Prototypes to Speed HDTV Standards

In addition to the above long-term proposals, two more immediate proposals can also be made. For example, DARPA and other public agencies could fund the development of HDTV prototype equipment in order to minimize the time required to adopt a distinctive U.S. HDTV standard. Requests for proposals would be designed with an eye to helping the United States incorporate technological advantages into products and maximize the scope of spinoffs to related electronics endeavors.

7.5.6 Reexamine Existing Governmental Research Programs to Get Better Spinoffs for HDTV Technologies

Another short-term proposal would be to reexamine existing programs with an eye toward slight changes that would help promote participation in HDTV markets. DARPA, the National Science Foundation, and other public agencies would evaluate such programs (for example, in multiprocessing or broadband switching) with regard to the ways they relate to a national HDTV strategy. Managers of these programs would be educated about the importance of the United States' reentry into consumer electronics. Wherever it is possible to generate important spinoffs for HDTV technologies -- for instance, through a minor reorientation of the terms of the project -- this should be done. Special effort should be made to assure that the results of these programs are widely diffused among U.S. firms.

65. Letter from Jack Tramiel, Chairman, Atari Corporation, to Charles Sporck, President and CEO, National Semiconductor Corporation, June 13, 1989.

7.6 Changes In Economy-Wide Policies

The policies described above would not involve any fundamental changes in U.S. macroeconomic or regulatory policies. However, judicious changes in economy-wide policies could provide an underpinning for the success of the industry-specific policies already discussed. These changes include:

- 1) making the research and development tax credit permanent,
- 2) relaxing restrictions in the National Cooperative Research Act of 1984,
- 3) adopting a graduated capital gains tax to increase the rewards to firms making investments in new capital equipment,
- 4) shifting the composition of federal spending toward education and worker training, infrastructure, and commercial science and technology,
- 5) vigorous enforcement of antidumping and unfair trade practices under the Omnibus Trade Act of 1988, and
- 6) establishing a national commission on technology to establish priorities for future public funding of research and development consortia.⁶⁶

66. For a lengthier discussion of these proposals see Jeffrey A. Hart and Laura Tyson, "Consumer Electronics, HDTV, and the Competitiveness of the U.S. Economy," unpublished manuscript, Berkeley Roundtable on the International Economy, University of California, Berkeley, February 1, 1989.

Table 1

World Production of Electronic Equipment, 1988 and Projections for 1992, in billions of dollars.

Year	N. Amer.	Japan	W. Europe	ROW	Total
1988	271.3	146.9	138.0	117.9	674.1
1992	361.4	184.8	186.0	204.9	937.1

Production of Consumer Equipment, in billions of dollars

Year	N. Amer.	Japan	W. Europe	ROW	Total
1988	18.3	49.0	20.0	48.6	135.9
1992	21.7	49.7	21.9	92.9	186.2

Proportion of Electronic Production Accounted for by Consumer Production (in percentages)

Year	N. Amer.	Japan	W. Europe	ROW	Total
1988	6.7	33.4	14.5	41.2	20.2
1992	6.0	26.9	11.8	45.3	19.9

Source: Dataquest.

Table 2

Global Markets for Electronics, 1984-88 (in billions of dollars).

Region	1984	1985	1986	1987
USA	169	166	173	183
Japan	71	75	104	125
W. Europe	79	87	116	122
Other^a	16	21	27	31
Total^b	335	349	420	461

Notes: a. Hong Kong, Singapore, Korea, and Taiwan

b. These totals are not consistent with Dataquest estimates. The EIAJ uses different definitions for the various branches of electronics.

Source: Electronic Industries Association of Japan (EIAJ), Facts and Figures on the Japanese Electronics Industry: 1988 Edition (Tokyo: 1988), p. 17.

Table 3

Factory Sales of Consumer Electronic Products in the United States, 1977-1987, in millions of dollars, including imports.

Year	Mono TVs	Color TVs	Proj. TVs	VCRs	Video Disc	Audio Systems	Audio Comp.
1977	530	3289	---	180	--	606	1275
1978	549	3674	---	326	--	748	1143
1979	561	3685	---	389	--	748	1178
1980	588	4210	---	621	--	809	1424
1981	505	4349	287	1127	55	720	1363
1982	507	4253	236	1303	54	573	1181
1983	465	5002	268	2162	81	630	1268
1984	419	5538	385	3585	45	976	913
1985	309	5562	488	4738	45	1372	1132
1986	328	6024	529	5258	45	1370	1358
1987	287	6271	527	5093	55	1048	1400

Year	Home Radio	Port. Audio	Car Audio	Audio Cass.	Video Cass.	Other ^a	TOTAL
1977	523	1208	534	---	---	---	8145
1978	436	1649	582	---	---	---	9107
1979	436	1739	623	---	---	---	9359
1980	468	1403	1368	---	---	7	10898
1981	501	1157	2000	242	---	191	12497
1982	530	971	2100	219	357	4542	16826
1983	565	1102	1900	249	580	6239	20511
1984	661	1191	2500	275	931	5615	23034
1985	379	1140	3000	277	1285	6511	26238
1986	408	1389	3500	304	1480	7885	29878
1987	409	1431	3800	326	1188	8516	30431

Note: a. This category includes personal computers and some other items which may be used for business purposes rather than personal entertainment. The EIA began to count personal computers only in 1982, which helps to account for the rapid growth in this area.

Sources: Electronic Industries Association (EIA), 1987 Electronic Market Data Book (Washington, DC: 1987), p. 6; EIA, 1988 Electronic Market Data Book, p.6.

Table 4**Production of Consumer Electronic
Equipment in Japan, in billions of yen.**

Year	TVs	VCRs	Total
1967	133.2		133.2
1968	278.6		278.6
1969	503.7		503.7
1970	681.3		681.3
1971	608.2		608.2
1972	715.0		715.0
1973	686.2		686.2
1974	615.1		615.1
1975	584.5		584.5
1976	768.1		768.1
1977	700.8		700.8
1978	617.3	204.1	821.4
1979	640.8	296.2	937.0
1980	711.9	562.8	1,274.7
1981	739.0	1,086.8	1,825.8
1982	683.1	1,285.0	1,968.1
1983	684.6	1,514.0	2,198.6
1984	755.8	2,090.0	2,845.8
1985	897.1	1,889.2	2,786.3
1986	723.8	1,659.4	2,383.2
1987	765.1	1,241.5	2,006.6

Source: Electronic Industries Association of Japan.

Table 5

Balance of Trade in Consumer Electronics, Japan, 1978-1987, in trillions of yen.

Year	Exports	Imports	Balance
1978	1.352	.021	1.331
1979	1.480	.037	1.443
1980	2.047	.038	2.009
1981	2.600	.033	2.567
1982	2.508	.026	2.482
1983	2.702	.020	2.682
1984	3.306	.023	3.283
1985	3.519	.024	3.495
1986	2.601	.032	2.569
1987	1.939	.060	1.879

Source: Electronic Industries Association of Japan, Facts and Figures (1988), pp. 36-45.

Table 6

U.S. TV Set Production, 1988.

Name of Firm	Plant Type	Location	Employees	Annual Production
Bang & Olufsen/ Hitachi	assembly	Compton, CA	n.a.	n.a.
Goldstar	total	Huntsville, AL	400	1,000,000
Harvey Indus.	assembly	Athens, TX	900	600,000
Hitachi	total	Anaheim, CA	900	360,000
JVC	total	Elmwood Park, NJ	100	480,000
Matsushita	assembly	Franklin Park, IL	800	1,000,000
American Kotobuki (Matsushita)	assembly	Vancouver, WA	200	n.a.
Mitsubishi	assembly	Santa Ana, CA	550	400,000
Mitsubishi	total	Braselton, GA	300	285,000
NEC	assembly	McDonough, GA	400	240,000
Orion	assembly	Princeton, IN	250	n.a.
Phillips	total	Greenville, TN	3,200	2,000,000
Samsung	total	Saddlebrook, NJ	250	1,000,000
Sanyo	assembly	Forrest City, AR	400	1,000,000
Sharp	assembly	Memphis, TN	770	1,100,000
Sony	total	San Diego, CA	1,500	1,000,000
Tatung	assembly	Long Beach, CA	130	17,500
Thomson	total	Bloomington, IN	1,766	3,000,000
Thomson	components	Indianapolis, IN	1,604	n.a.
Toshiba	assembly	Lebanon, TN	600	900,000
Zenith	total	Springfield, MO	2,500	n.a.

Note: When plant type is "total," then manufacturing involves more than assembling of knocked-down kits. Plants that manufacture just the cabinets for televisions are not included in this list.

Source: Electronic Industries Association, HDTV Information Center.

Table 7

U.S. Cathode Ray Tube Production, 1988.

Name of Firm	Location	No. of Employees	Production Capacity
Matsushita/Philips	Troy, OH	100-200	1,000,000
O-I/NEG TV ^a	Columbus, OH	800	n.a.
"	Pittston, PA	750	n.a.
Philips	Ottawa, OH	2,300	3,000,000
Thomson	Marion, IN	1,982	n.a.
Toshiba	Horseheads, NY	1,000	1,000,000
Zenith	Melrose Park, IL	3,000	n.a.

Note: a. O-I/NEG TV is a joint venture between Owens-Illinois and Nippon Electric Glass to make very large television tubes -- up to 45 inches.

Source: Electronic Industries Association, HDTV Information Center.

2.0 INTRODUCTION

The question of whether the U.S. will occupy a competitive position in the emerging market for high definition television products and related technologies has become symbolic of the broader question of whether the U.S. will regain its competitive strength in world markets. As HDTV has become a symbol of the nation's competitive challenges, Congressional enthusiasm for national programs to promote U.S. participation in HDTV has mounted. Congress is not alone in its enthusiasm. Secretary of Commerce Robert Mosbacher has stated his support for promoting a U.S. HDTV industry, as have a number of key officials in the Department of Defense.² {Currently, Commerce enthusiasm for direct support appears to have waned. -ed.}

It is one thing to think of HDTV as a national symbol, another to devise practical policies which permit U.S. participation in HDTV markets to contribute to overall competitiveness. Participation in HDTV research, development, production and commercialization will be absolutely crucial for maintaining or increasing participation in future markets for consumer electronic equipment. It will be important, but probably not crucial, for maintaining or increasing U.S. participation in other electronics markets. It can contribute, but perhaps only at the margin, to making U.S. manufacturing more competitive. While electronics is clearly a strategic industrial sector for the United States, it still remains to be determined, however, whether it is necessary for the United States to have a strong consumer electronics presence. The role of U.S. participation in HDTV needs to be kept in perspective and public policy enthusiasm for activism in HDTV must be juxtaposed with a realistic appraisal of costs and opportunities.

This report on HDTV comes out of a long-term commitment on the part of the researchers at the Berkeley Roundtable on the International Economy (BRIE) to understand the role of technology, policy, and business strategy in international competitiveness. BRIE has argued, in a variety of works, that strength in electronics technology and manufacturing is strategic for maintaining and increasing international competitiveness in the contemporary world economy.³ In particular, the strength of the microelectronics or semiconductor industry of the larger industrial countries is a key

2. Eduarico Lachica, "Commerce-Designate Mosbacher Vows Policies to Boost U.S. Competitiveness," New York Times, (January 25, 1989), p. A22. Secretary Mosbacher backed away from his early statements about HDTV in June 1989, when the American Electronics Association (AEA) presented a report in which they requested 1.35 billion dollars in subsidies and loan guarantees from the government for a national program to promote HDTV.

3. Stephen S. Cohen and John Zysman, Manufacturing Matters: The Myth of the Post-Industrial Economy (New York: Basic Books, 1987), especially chapter 10.

Table 8

Market Shares of the U.S. Color Television Market, 1964, 1975 and 1986.

Firm	National Origin	1964	1975	1986
RCA	USA	42	19	18
Zenith	USA	14	24	16
Philips	Netherlands	--	7	10
Matsushita	Japan	--	8	9
Sanyo	Japan	--	--	7
Sony	Japan	--	6	6
GE	USA	--	6	6
Sharp	Japan	--	--	3
Hitachi	Japan	--	--	3
Toshiba	Japan	--	--	2
Warwick	USA	8	8	--
Motorola	USA	8	--	--
Rockwell	USA	7	3	--
Magnavox	USA	6	--	--
GTE-Sylvania	USA	4	4	--
Others	Various	11	15	20

Note: RCA and GE merged in 1987; RCA/GE consumer electronics was acquired by Thomson in 1987.

Source: David H. Staelin, "The Decline of U.S. Consumer Electronics Manufacturing: History, Hypotheses, and Remedies," Consumer Electronics Working Group, Commission on Industrial Productivity, MIT, Cambridge, MA, April 1988, p. 40.

Table 9

Alternative Delivery Methods for HDTV Signals.

	Terrestrial Broadcast	<i>Cable</i> Cable	Coaxial DBS	Fiber Optics
compatible with existing system of local broadcast & cable delivery?	yes	yes	no	yes, if cable operators convert to fiber
coverage of US households?	nearly universal	~60 percent	potentially universal	slow spread to rural areas
preserves "free television"?	yes	no	no	no
quality of images?	satisfactory	satisfactory	high	high
potential for interactive services?	no	limited	no	extensive
expense to deliverer to convert to HDTV?	high	high	low, but new satellites needed	low, but need to develop new switches
Impact on demand for spectrum?	positive	positive	positive	negative
permits use of portable TVs?	yes	only if near cable connector	yes	only if near fiber connector
costs to consumer beyond TV receiver?	none	subscriber fees	subscriber fees plus dish and decoder	subscriber fees
maintenance costs for deliverer?	low	high	low	lower than cable
vulnerability of system to disruptions?	low	problems with weather	problems with weather & sunspots	low

Table 9a

Innovations in IBM-Compatible Personal Computer Displays.

Date Name of Innovation

1981	IBM Monochrome Display Adapter
1981	IBM Color Graphics Adapter (CGA)
1982	Hercules Graphics Card
1984	IBM Extended Graphics Adapter (EGA)
1985	NEC Multiscanning Monitor
1987	IBM Video Graphics Array (VGA)
1987	IBM 8514/A Interlaced 1,024 by 768 Monitor
1988	Super VGA
1989	Compaq Noninterlaced 1,024 by 768 Monitor

Source: "The Resolution Time Line: Additional Pixels Enhance Quality," PC Magazine, May 16, 1989, pp. 96-7.

Table 10

Advanced Television Sales to U.S. Households: Comparison of Projections in millions of units.

Year	Nathan Associates	Darby Associates	AEA Report
1990			.001
1991			.005
1992			.007
1993	.700		.010
1994	1.600		.020
1995	3.300		.030
1996	4.800		.080
1997	6.500	1.000	.100
1998	8.500	1.600	.250
1999	9.500	2.600	.500
2000	10.400	4.100	1.000
2001	11.300	6.600	1.600
2002	12.200	10.500	2.600
2003	13.100	11.500	4.900
2004		12.700	6.500
2005		14.000	6.700
2006		15.400	6.800
2007		16.900	6.900
2008		18.600	7.900
2009			8.900
2010			11.000

Sources: see footnotes 37-39.

Table 11

Comparison of the Projected U.S. Market for HDTV Receivers in Three Reports, in millions of dollars.

Year	AEA	Darby Low	Darby High	Nathan Assoc.
1990	4			
1991	18			
1992	25			
1993	29			1,600
1994	54			3,600
1995	75			7,100
1996	176			9,700
1997	200	400	800	12,900
1998	450	600	1,200	16,300
1999	800	1,100	2,200	17,200
2000	1,500	1,600	3,200	18,500
2001	2,080	2,700	5,300	18,200
2002	2,860	5,100	8,300	19,000
2003	4,900	4,100	9,300	19,700
2004	5,850	4,600	10,200	
2005	5,360	5,600	11,100	
2006	5,100	6,200	12,400	
2007	4,830	6,700	13,500	
2008	5,135	7,500	14,900	
2009	5,563			
2010	6,600			

Note: The Darby report provided high and low estimates of the market. The figures reported here were calculated from the cumulative values given in Table 12 on p. 36. All the above estimates are based on expected retail prices.

Sources: See footnotes 37-39.

Table 12

Unit Price Assumptions of the Three Reports.

Year	Nathan	Darby-Hi	Darby-Lo	AEA
1990				4000
1991				3600
1992				3500
1993	2286			2900
1994	2250			2700
1995	2150			2500
1996	2020			2200
1997	1985	800	400	2000
1998	1918	1250	375	1800
1999	1811	1615	423	1600
2000	1779	1805	390	1500
2001	1611	1924	409	1300
2002	1557	2000	486	1100
2003	1504	2635	357	1000
2004		3189	362	900
2005		3686	400	800
2006		4156	403	750
2007		4586	396	700
2008		4968	403	650
2009				625
2010				600

Source: Computed by author from Tables 10-11.

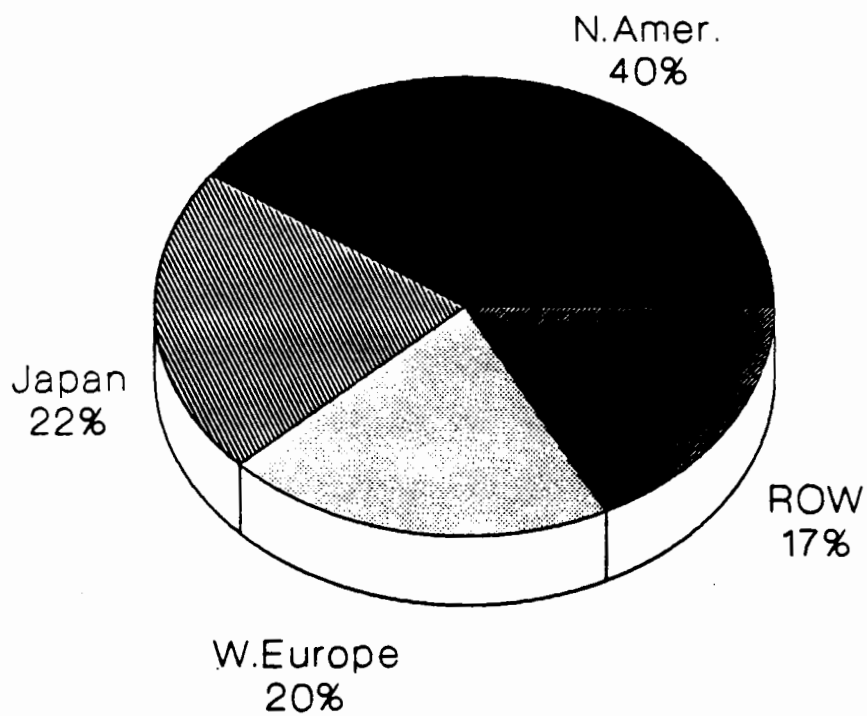
Table 13

Forecast of Worldwide HDTV Receiver Markets, in millions of dollars.

Year	U.S.	Europe	Japan	Other	Total	Cumulative Total
1990	4	4	80	4	92	92
1991	18	4	280	10	314	406
1992	25	7	480	10	522	928
1993	29	9	754	15	806	1,734
1994	54	14	945	16	1,028	2,762
1995	75	14	1,125	25	1,238	4,001
1996	176	22	1,364	32	1,594	5,595
1997	200	100	1,600	40	1,940	7,535
1998	450	270	1,800	54	2,574	10,109
1999	800	480	1,920	160	3,360	13,469
2000	1,500	1,500	2,400	1,050	6,450	19,919
2001	2,080	1,950	2,600	1,560	8,190	28,909
2002	2,860	2,640	3,300	2,090	10,890	38,999
2003	4,900	3,000	3,500	2,500	13,900	52,899
2004	5,850	4,050	4,050	3,060	17,010	69,909
2005	5,360	4,000	4,000	3,200	16,560	86,469
2006	5,100	4,125	3,750	3,525	16,500	102,969
2007	4,830	4,550	3,360	3,710	16,450	119,418
2008	5,135	4,550	2,600	3,575	15,860	135,279
2009	5,563	5,000	2,813	3,625	17,000	152,279
2010	6,600	5,100	2,700	3,600	18,000	170,279

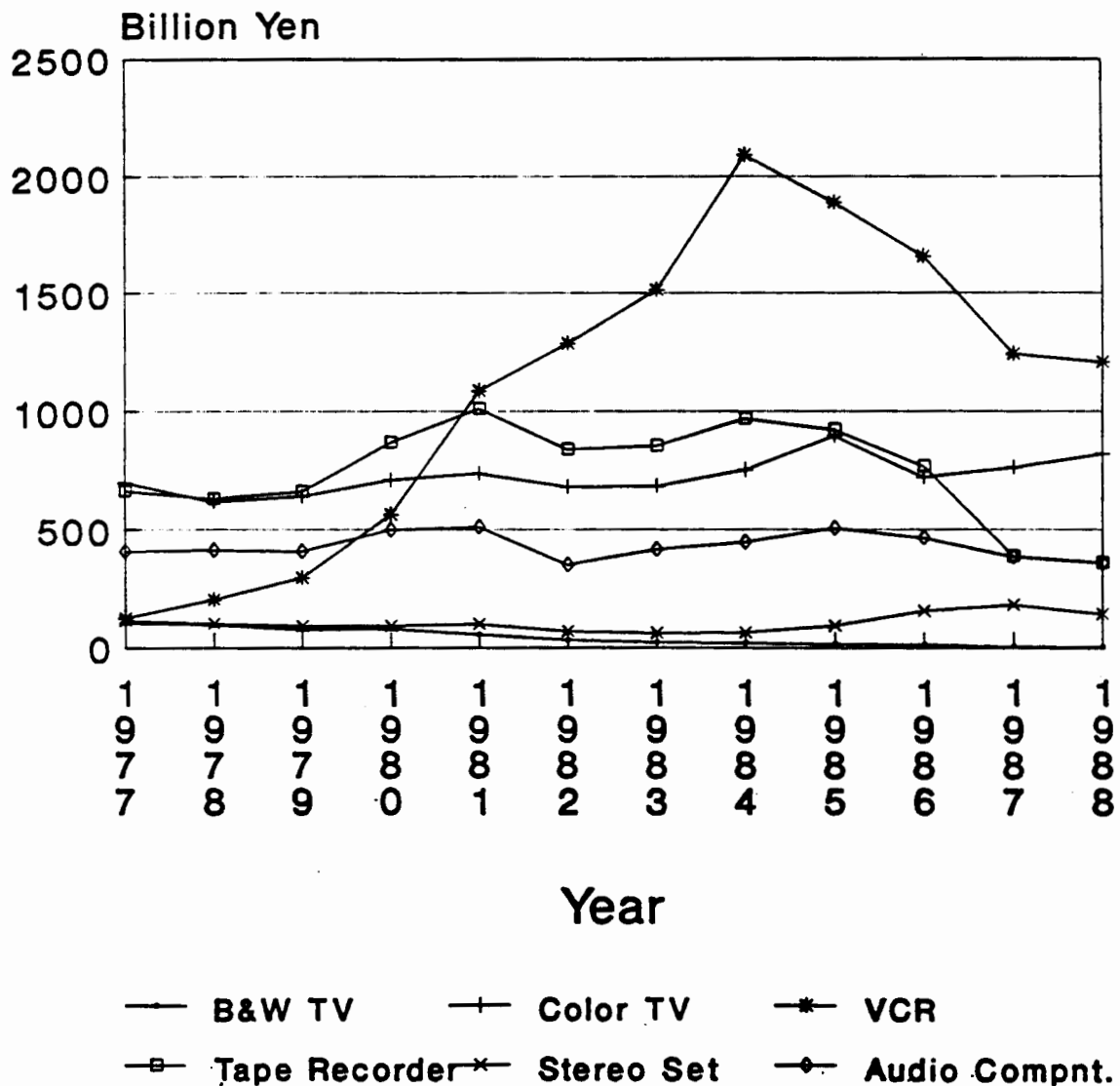
Source: See footnote 39.

Figure 1. Production of Electronic Equipment, 1988



Source: Table 1.

Figure 3. Production of Consumer Electronic Equipment in Japan

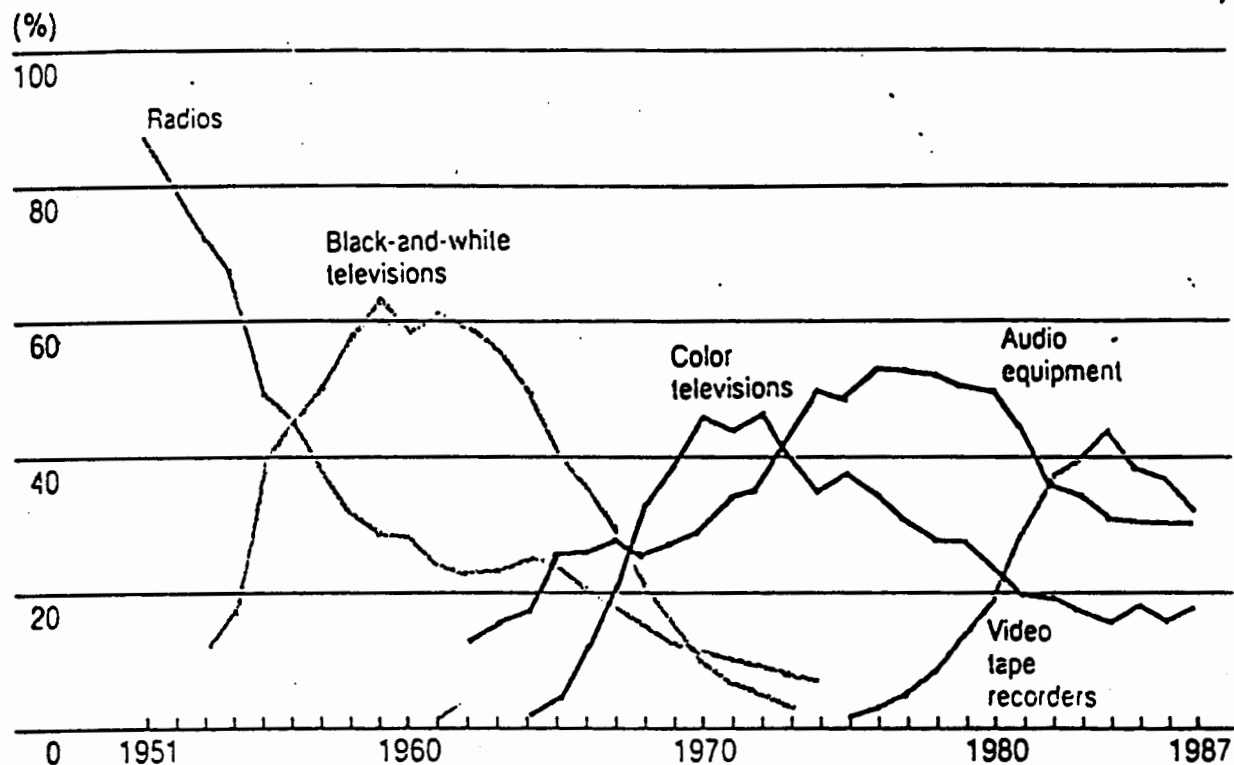


Source: MITI/EIAJ.

FIGURE 3a:

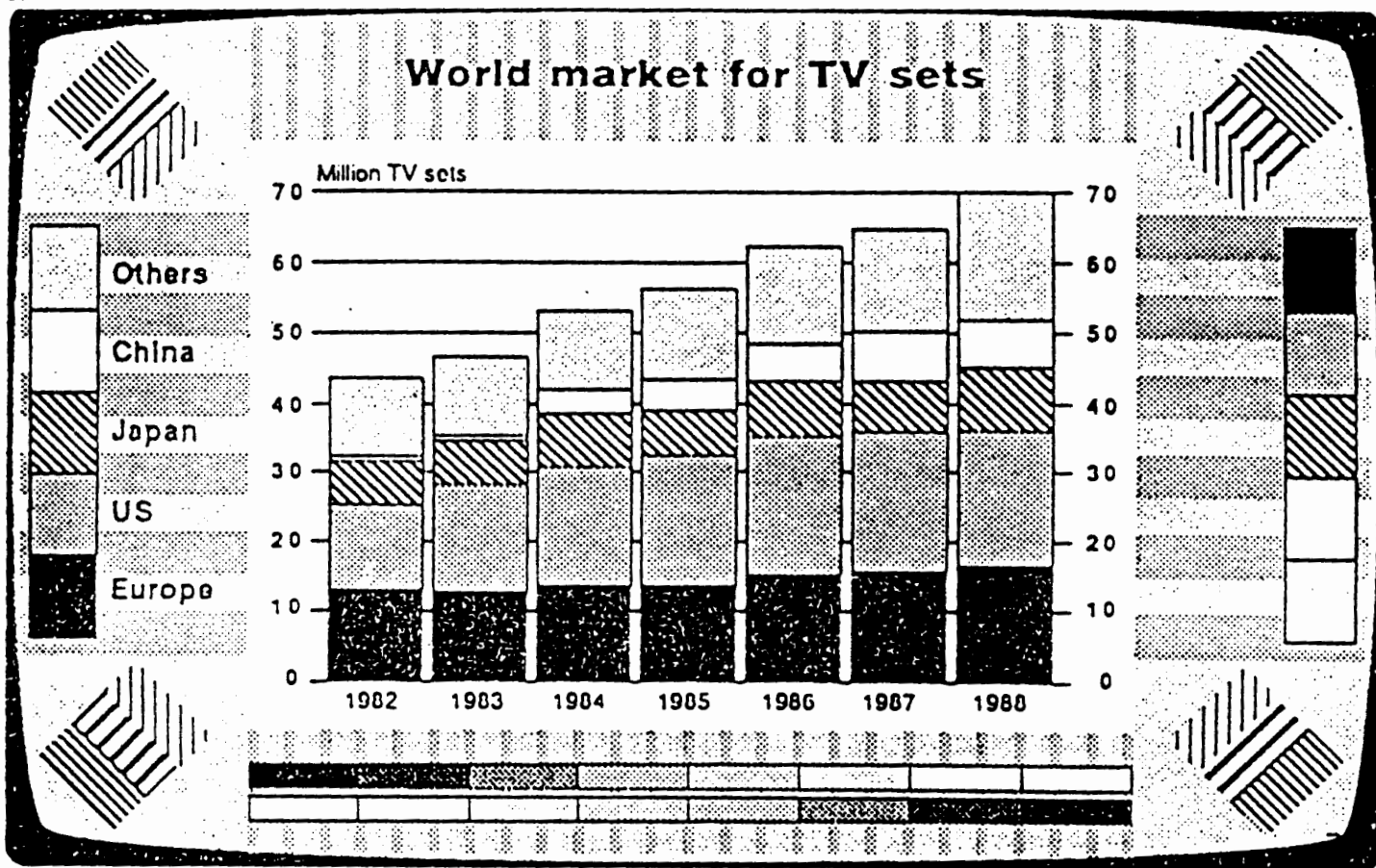
Production Composition of Principal Consumer Electronic Equipment

in Japan



Source: MITI-CPS.

FIGURE 4:



Source: BIS Mackintosh as cited in Jane Rippeteau, "Whose Hand Will Be On The Horizontal Hold," Financial Times, April 21, 1988, p. 17.

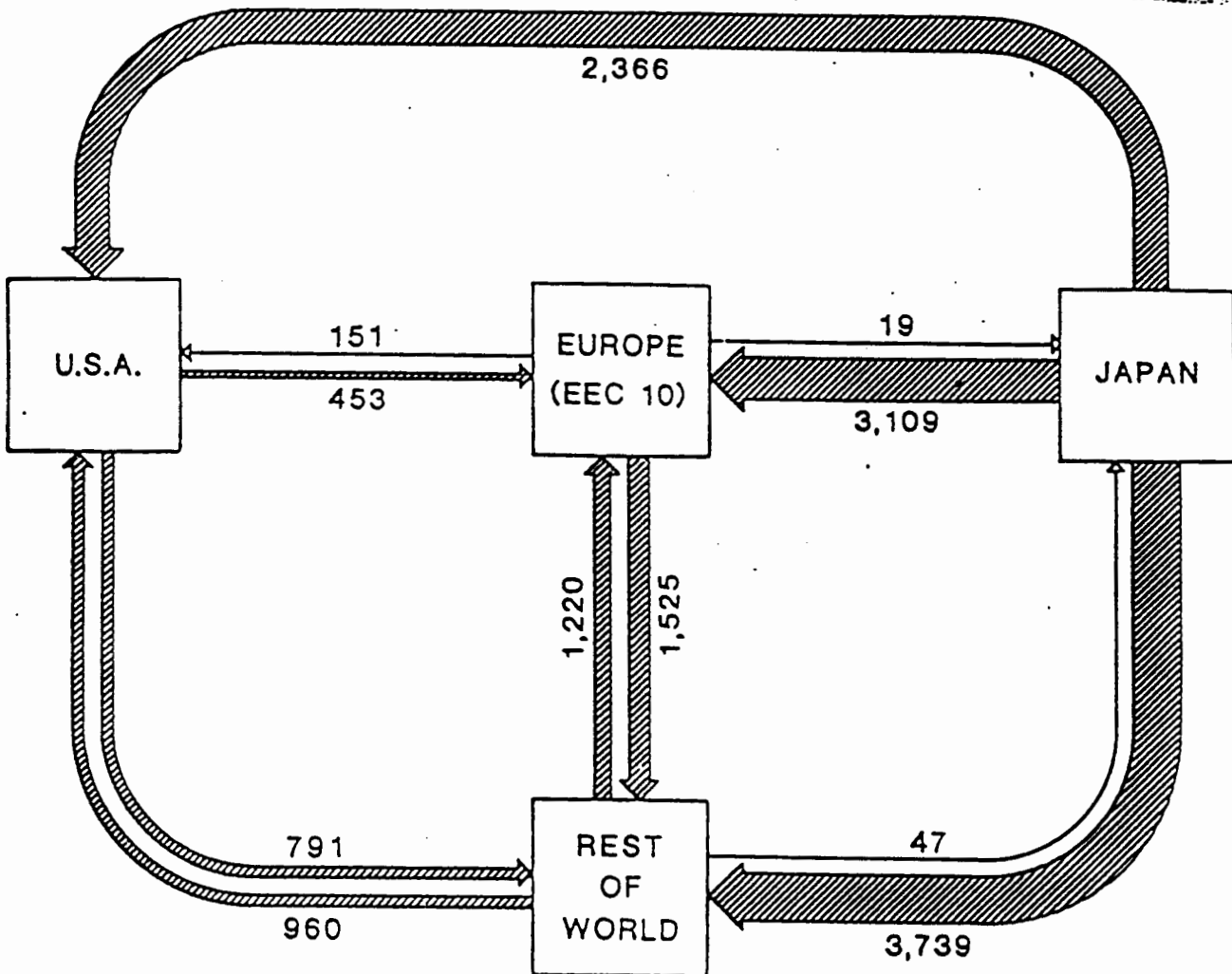
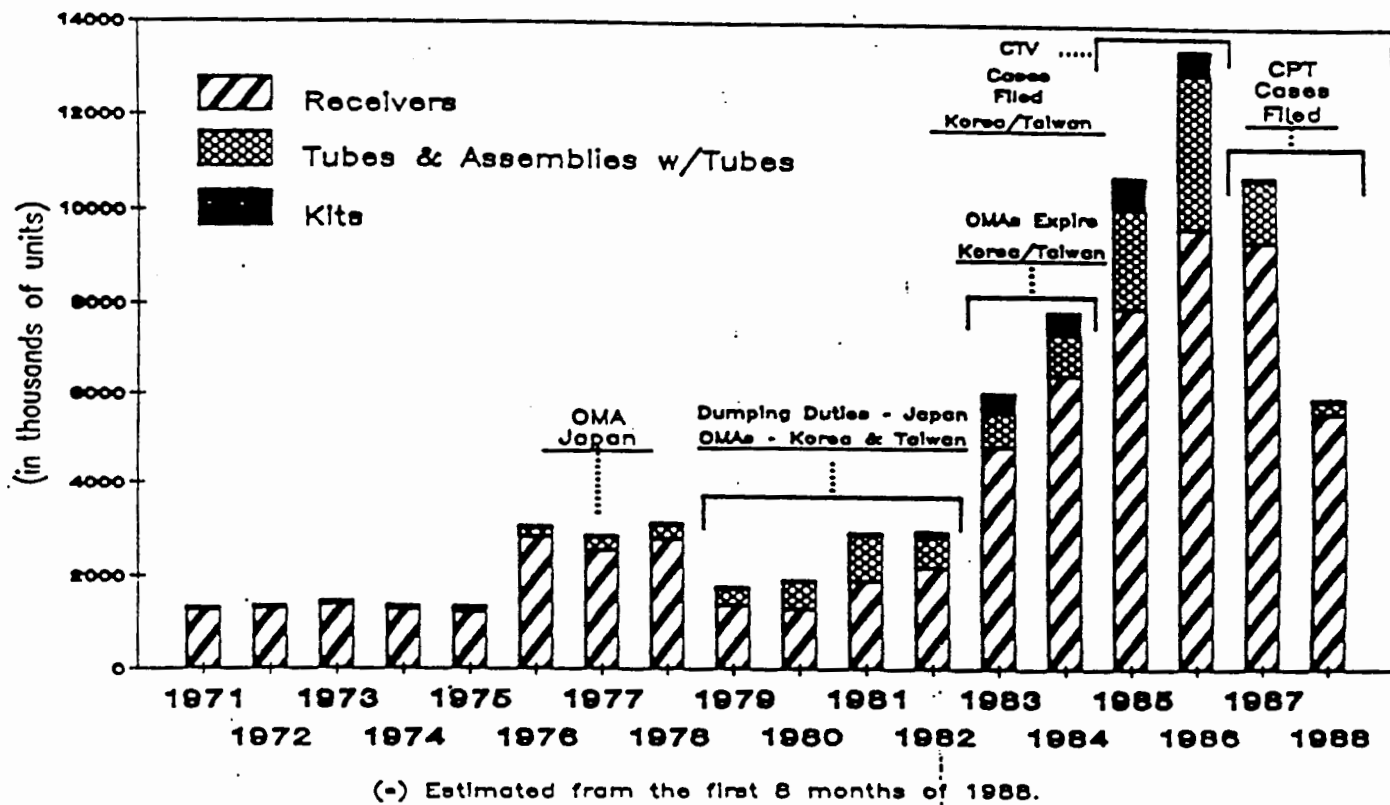


FIGURE 5: Trade Flows in Consumer Electronics, in millions of dollars, 1982

Source: Kevin Morgan and Andrew Sayer, Microcircuits of Capital (Boulder, CO: Westview Press, 1988), p. 106.

**FIGURE 6 U.S. IMPORTS OF COLOR TELEVISION SETS
COMPLETE RECEIVERS AND KITS,
PICTURE TUBES AND ASSEMBLIES WITH TUBES
ANNUAL 1971 - 1988 (*)**



Source: COMPACT, February 1, 1989.

years. It is possible that developments in CRT technology will make it possible for CRTs to be used as HDTV displays even after the development of inexpensive flat panels and projectors.³⁰ CRT will probably remain the technology of choice for small and inexpensive video displays. But there are important incentives for a wide variety of firms to develop improvements in non-CRT product and process technologies. While Japan dominates many aspects of LCD research, a number of U.S. firms have strengths in LCD, TFT, and light-shutter technologies. The development of indigenous non-CRT displays for HDTV will probably be accelerated by DARPA funding efforts.

4.3.3.4 Displays for Computers and Workstations

One argument that has appeared in the debate over public support for the development of HDTV technologies has been that the computer industry is likely to be more diligent in developing high-resolution, color displays than the traditional consumer electronics industry and that it is unlikely that the television industry will produce innovations in displays that will actually benefit the computer and telecommunications equipment business.³¹ It is true that there has been rapid development of computer displays in recent years. Table 9a shows the dates and names of important innovations in IBM-compatible personal computer displays since 1980.

Table 9a shows that the tendency in computer displays is toward higher resolution of color images. The degree of static resolution in computer monitors is higher than that of current television monitors, but most computer monitors are not capable of displaying full-motion video. In addition, while some computer monitors are capable of displaying color video images using analog signals and interlacing, there is a tendency for the most advanced computers and workstations with color graphics capabilities to use digital inputs and non-interlaced displays to maximize ease of viewing and to avoid flicker.

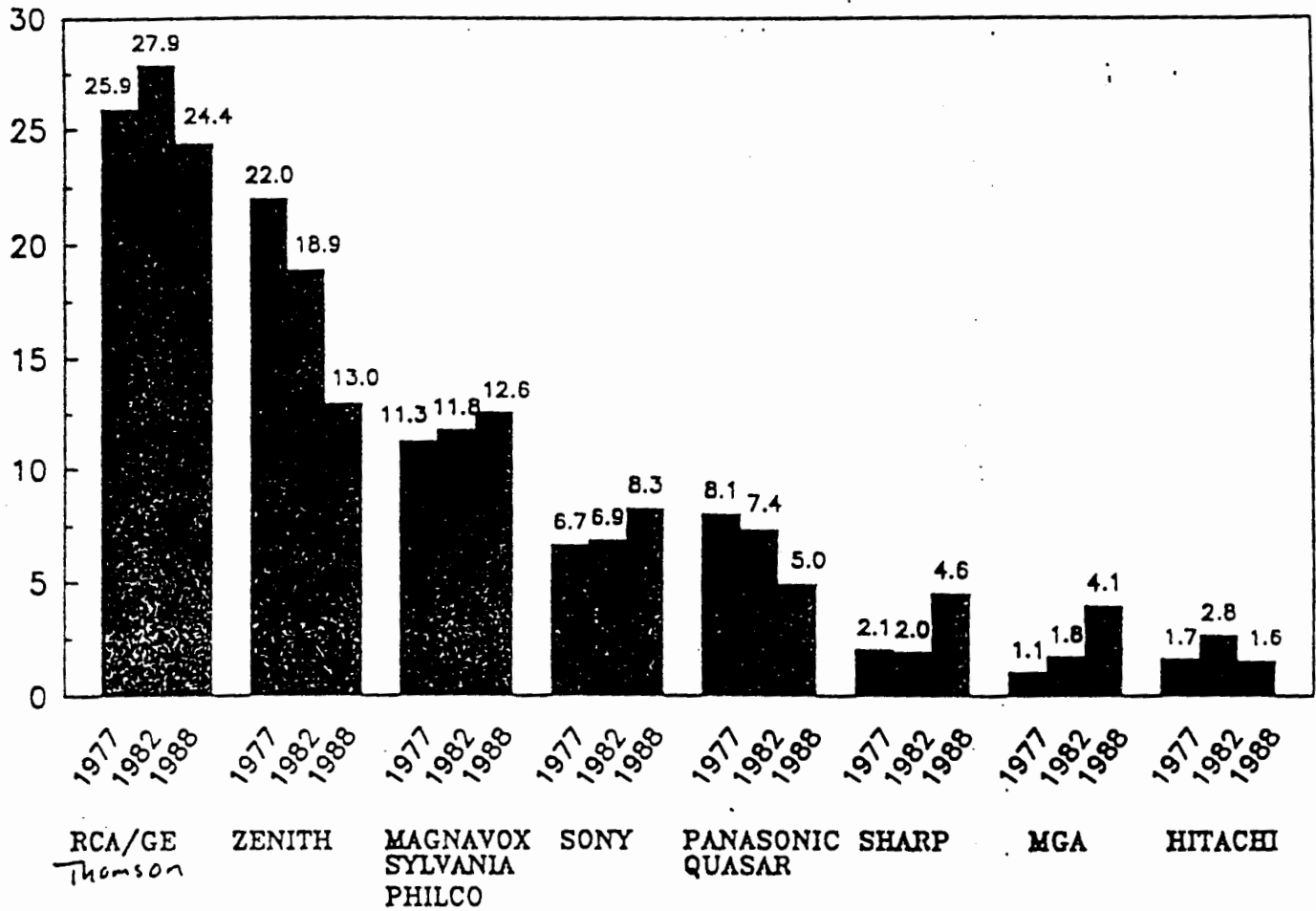
People do not use televisions the same way they use computers. Computers and workstations are generally used by individuals in rooms where there is little ambient light and do not require a wide viewing angle, unlike television displays. Computer displays do not have to be large, and especially not as large as HDTV displays are likely to be. Of course, there will be some need for large high-resolution computer displays. Such displays will be useful for making presentations to large audiences, for allowing teams of individuals to work on the same image, or for simulating the

30. I am thinking here primarily of efforts to eliminate tension masks and to bend the electron beam so that large but less bulky CRTs can be made inexpensively.

31. See Gilder, "IBM TV," op.cit.

**FIGURE 7: U.S. COLOR TV MARKET SHARE
(1988 IS FIRST HALF DATA)**

% SHARE



Source: Thomson Consumer Electronics, Indianapolis.

HOME SATURATION GROWTH
CONSUMER ELECTRONICS PRODUCTS

FIGURE 9:

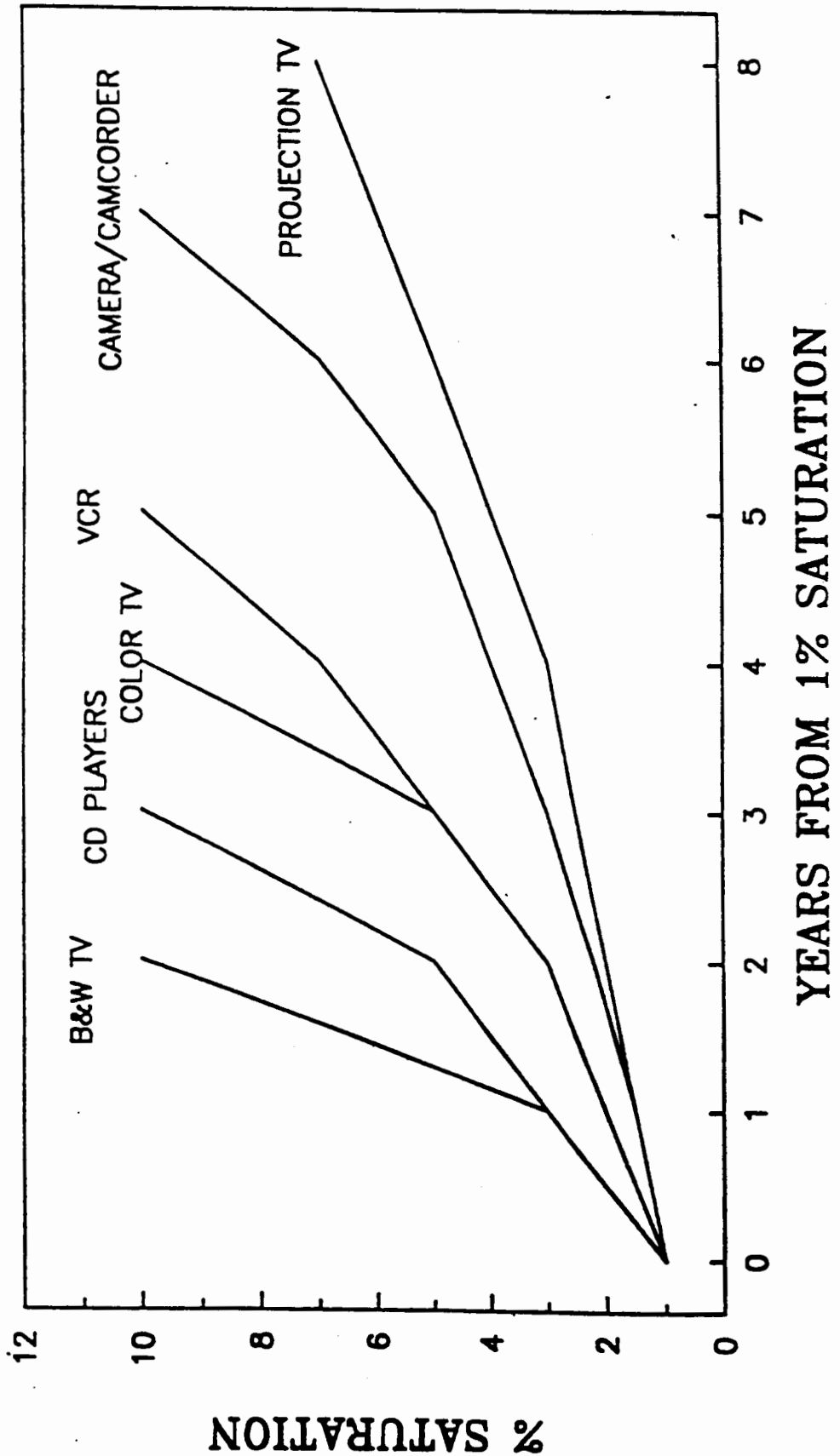
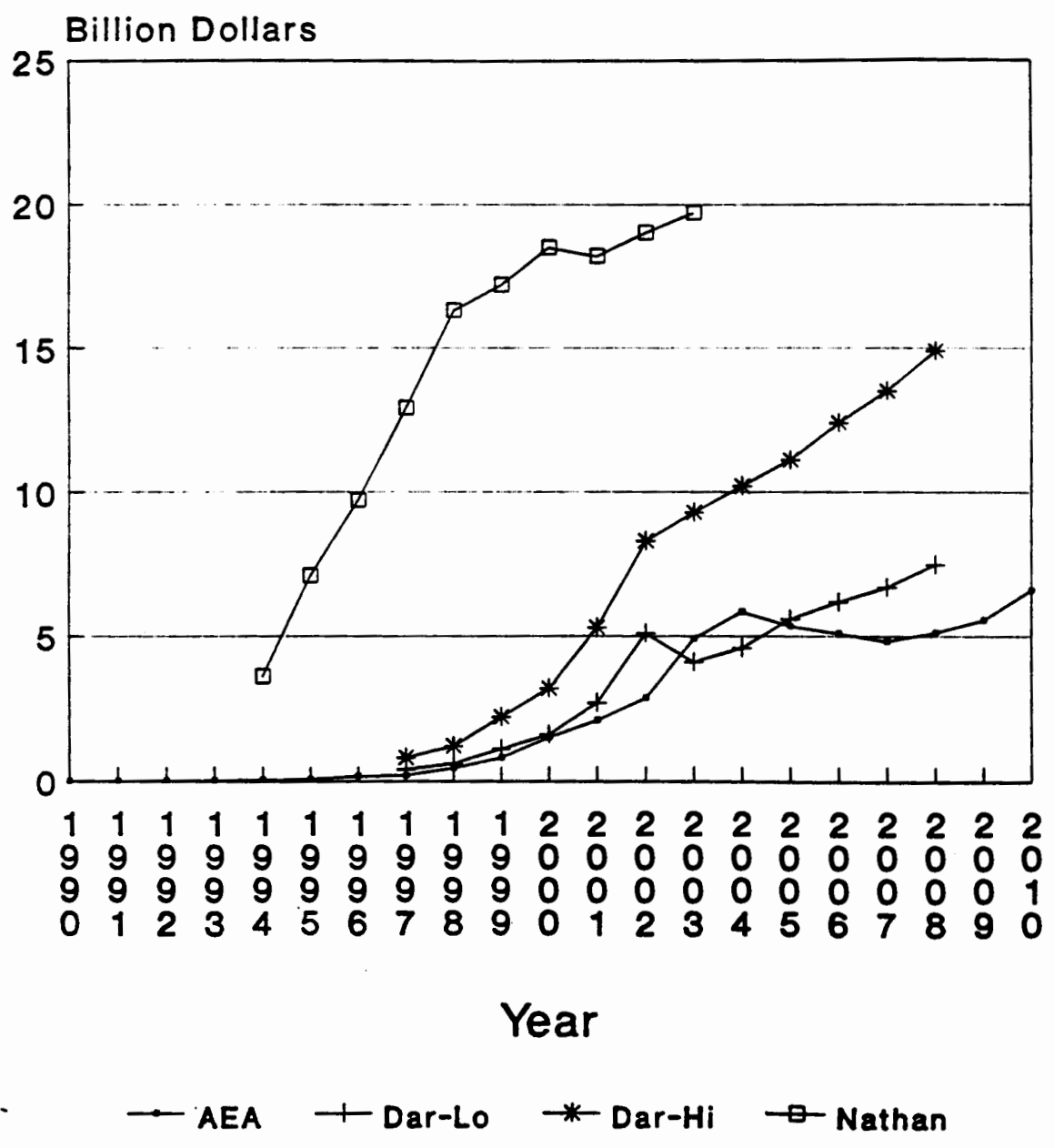


FIGURE 11. Comparison of Projected U.S. Market for HDTV Receivers



Source: Table 11.

PROJECTED PENETRATION RATES

HDTV Receivers and VCRs

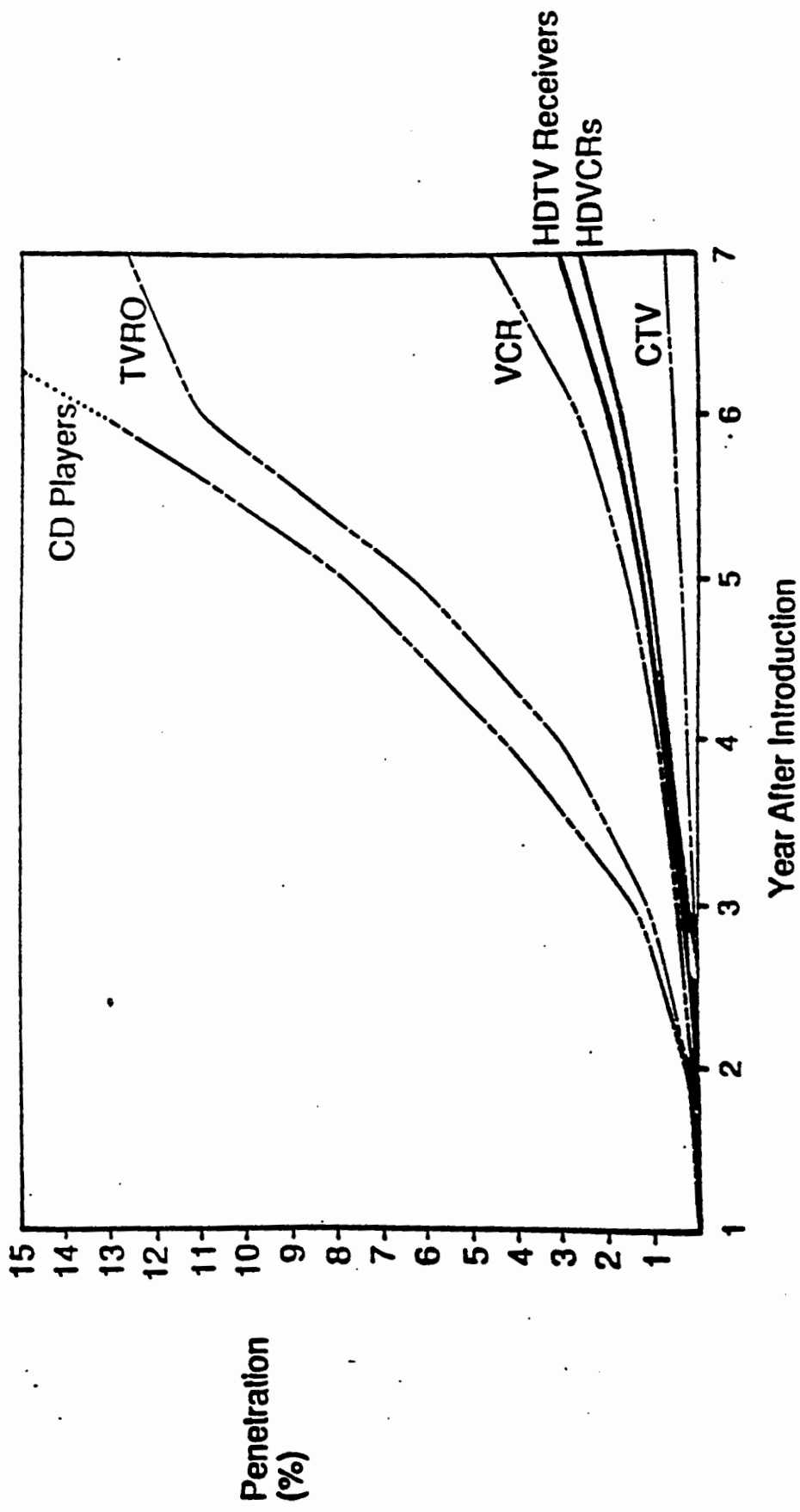


FIGURE 12:

Source: BCG Analysis

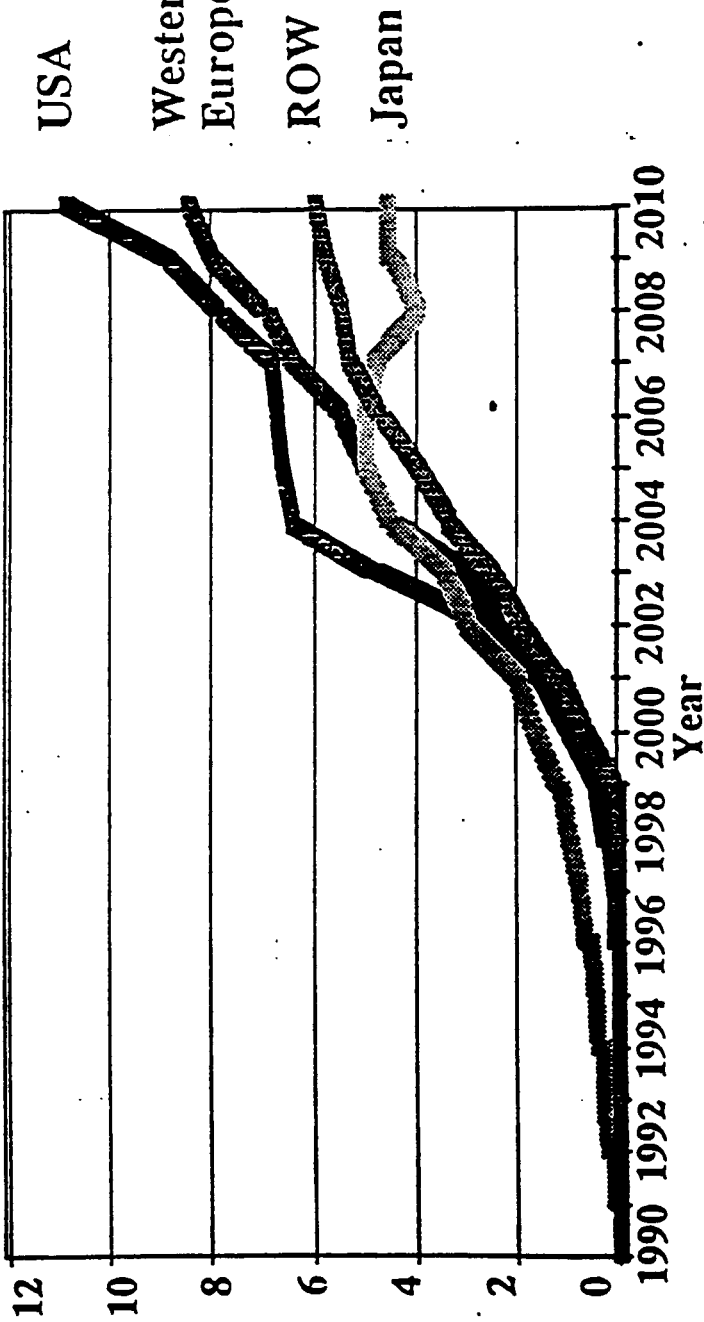
FIGURE 15:

BIS Mackintosh



Worldwide HDTV Sales Forecast 1990 - 2010

Millions of Units



Forecasts are for full HDTV and do not include earlier sales of EDTV 625 line Widescreen MAC sets

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