Analysis of Major Issues in Commercializing HDTV

by

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Submitted to the Sloan School of Management
in Partial Fulfillment of
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ABSTRACT

High-definition television (HDTV) is a revolutionary new television technology that can deliver movie-quality, wide-screen pictures to homes with stereo sound comparable to the best compact discs. The significance of HDTV goes well beyond home entertainment, however. Many view HDTV as a key element of the information society of the future when "information networking" will give people access to multimedia communications around the globe. In addition, HDTV will have numerous applications in commercial and industrial sectors.

The market for HDTV is potentially very large. The Japanese Ministry of Posts and Telecommunications (MPT) predicts that annual sales of television-related HDTV equipment in Japan will reach 3.4 trillion yen ($26 billion) by the year 2000. Between 1990 and 2000, overall HDTV-related sales in Japan will total 14.5 trillion yen ($112 billion), according to MPT. The American Electronics Association (AEA) estimates that just consumer purchases of HDTV receivers and VCRs in 2010 will be worth $10.9 billion in the United States. The projections for the European market are of a similar magnitude.

This thesis focuses on HDTV mainly as a consumer product and analyzes the regulatory, technical, economic and market factors that will influence its market penetration. A discussion of the obstacles faced by B&W TV and color TV during their early years is included as background material.

Provided first is an overview of the key product attributes, the standards issues and the status of HDTV development in Japan, Europe and the U.S. Next, results of market projections by several organizations are presented, and efforts to promote the use of HDTV equipment are discussed. A variety of factors that will shape the growth pattern of HDTV and determine its eventual fate are then analyzed. Finally, an assessment of how the HDTV market might grow and how HDTV may become a home information appliance is given.

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Chapter 1
Product, Applications and Standards

Having essentially remained unchanged for 50 years, the television technology is poised on the threshold of a revolution. HDTV not only promises to deliver wide, crisp, cinema-like pictures with the crystal-clear sound of compact discs, but may also be smart enough to store and retrieve electronic still pictures, allow two-way video communication, and receive programs in different formats. With the potential markets forecast to be worth billions of dollars, a global race is underway to turn HDTV into a commercial reality.

Japan has a clear lead in the race to bring HDTV to the world. NHK, the country’s public broadcasting company, has spent over 20 years and $500 million in developing HDTV technology; Japanese industry has spent another $700 million to $1.3 billion in designing, refining and getting to market the required components.¹ Over the years, government and industry have worked closely together to develop and promote HDTV, and to hammer out the broadcast standards. The Japanese have also tried very hard to make their system as the world standard, but have met with little success so far.

MUSE, Japan’s satellite-based system, is currently the most mature of the various HDTV proposals around the world. It is the only system for which supporting products are commercially available. Studio production equipment manufactured to NHK specifications has been on the market since 1984; HDTV receivers first became available in Japan in late 1990. More important, Japanese industry has dabbled extensively with most of the essential HDTV components and is further ahead in producing them at realistic prices.² Japan launched into the HDTV era by broadcasting the Seoul Olympics in September 1988. From June 1989 to November 1991, NHK transmitted 1-hour daily

broadcasts to help stir up consumer interest. Since last November, the broadcasts have been increased to 8 hours a day.

Europe is not far behind. At a 1986 meeting of the CCIR, Europe scuttled Japan's bid to make the NHK system the world standard. Fearing Japanese domination of the European markets, Europe's 19-nation Eureka consortium then organized Eureka Project 95 in June 1986 to develop an all-European HDTV system. Eureka-95 consists of 32 organizations from 9 countries, and is funded with $720 million - 40% from EC governments.\(^3\) The program spent $400 million during the first 4 years,\(^4\) and has made rapid progress in developing HDTV production, transmission and reception equipment and standards. In September 1988, Europe's HD-MAC HDTV system along with a complete line of supporting hardware was demonstrated in Brighton, England. European manufacturers have made prototypes of cameras, VCRs, encoders, decoders, transmitters and receivers since September 1989. In May 1990, Philips and Thomson created a formal alliance to perfect HD-MAC, and pledged $4 billion more to the task.\(^5\) Satellite broadcasts using the wide-screen ED-MAC system began in early 1991. Experimental HD-MAC broadcasts are planned for 1992, when Eureka-95 will transmit the Summer Olympics from Spain. Limited HD-MAC broadcasts will begin in 1994. By 1995, European broadcasters plan to offer full HDTV satellite and cable services.

While HDTV has been heavily subsidized, strongly promoted and carefully orchestrated by European and Japanese governments, industry is carrying most of the burden of developing and implementing HDTV in the U.S. Except for a $30 million funding from DARPA to develop high-resolution displays and processors,\(^6\) there has been little government-industry cooperation. In May


\(^4\)Translated, HDTV Means 'Beat Japan', Business Month, June 1990.


1989, the American Electronics Association, representing 36 U.S. firms, asked for $1.35 billion in low-cost loans and loan guarantees to help U.S. firms develop HDTV technology. But the proposal met with considerable skepticism in Washington and eventually fizzled. The Congressional Budget Office questioned the premise that HDTV was an important market for U.S. firms. Lacking government support, the U.S. industry's total investment in HDTV was estimated to be less than $100 million as of June 1990.

Given Japan's lead, early U.S. response was largely focused on catching up with the Japanese, and it looked as though the U.S. was out of the running altogether. However, appearances can sometimes be deceptive. Driven by the threat of being locked into a Japanese HDTV standard, U.S. companies have come up with impressive alternatives that have eclipsed both MUSE and HD-MAC. Since the introduction of an all-digital version of HDTV by General Instrument in June 1990, five of the six systems proposed to the FCC have become totally digital. Backers of digital HDTV say that it will offer viewers the chance to experience on the television screen what so far (thanks to the CD player) they have been able only to hear: absolute purity of signal. But the fact remains that the U.S. still has not chosen a transmission standard. If testing of the proposed systems goes on schedule, the FCC will select a standard in 1993. As a result, the U.S. may have HDTV by 1995.

What is HDTV?

HDTV is the most significant advance in television since the introduction of color in 1954. In addition to clearing up some of the annoying defects that

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9 Translated, HDTV Means 'Beat Japan', Business Month, June 1990.

10 MUSE and HD-MAC are little more than scaled-up versions of conventional TV. They allow wider screens and can display twice as many lines, but in all other respects, they operate almost the same. Being analog-based, they are technologically obsolete.
plague today's TV pictures - smeared colors in detailed patterns, flicker within and around objects, backward-spinning wagon wheels - HDTV promises to bring several other major improvements. Exhibit 1 shows the key differences between HDTV and conventional TV standards.

The first big leap HDTV takes is in picture quality. HDTV pictures are incredibly sharp and detailed, and have brighter, more vivid, realistic colors. The picture on current TV sets is produced by 525 scan lines with 30 frames (complete pictures) per second. Because HDTV scans roughly twice as many lines twice as often, it provides double the resolution of current sets. HDTVs that scan the whole picture in one continuous (progressive) sequence instead of interlacing two half-images 30 times a second, as NTSC sets do, further double the resolution and cut down flicker. When these advances in receivers are combined with the fact that HDTV signals transmit 5 times as much visual information as NTSC signals, the result is pin-sharp, detailed pictures that rival the quality of 35mm film. Because HDTV signals also carry 10 times the color information, HDTV pictures appear to be much more lifelike due to the greatly improved color rendition.

Next, to deliver the full impact of these detailed images, HDTV uses a bigger, wider screen, proportioned more like a movie screen. Research shows that viewers have a strong preference for screens 5 to 6 units wide by 3 units high - dimensions that correspond more closely to the human field of vision. HDTV thus expands today's squarish (4:3 width-to-height ratio) TV screen into a rectangle with an aspect ratio of 16:9. This wider screen almost matches the dimensions of today's movie-theater screens, which use an aspect ratio of either

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11A detailed description of the problems in NTSC television is given in Appendix A.
12Choosing the TV of the Future, Technology Review, April 1989.
1.85:1 or 2.35:1 for greater impact.\textsuperscript{16} Made-for-theater movies can thus be transmitted in a form much closer to their original composition. Also, because the ideal viewing distance for HDTV is only 3.3 screen heights compared to 7.1 screen heights for NTSC,\textsuperscript{17} HDTV provides the viewer a much larger field of view: 30-by-17 degrees versus 11-by-8 degrees for NTSC. And with the higher resolution of HDTV, screens can be much larger without sacrificing picture quality. NHK experiments, in fact, indicate that screens 40 to 60 inches in size will be necessary to fully experience the benefits of HDTV.\textsuperscript{18}

Finally, to create a true home theater, HDTV combines these big, wide-screen pictures with the crystal-clear sound of compact disc players. A 4-channel digital stereo system is adopted for this purpose. The system consists of 3 front speakers and 2 rear speakers: each front speaker carries an independent channel; the rear speakers "echo" those channels. The result is a concert-hall-like environment with rich sound coming to listeners from all directions.

What will watching TV be like with HDTV? First, because of the high quality of its pictures, HDTV will reveal minute details with unflinching clarity. It will be possible, for example, to differentiate silk from nylon on the screen. Second, because of the wider aspect ratio, movies can be watched in full size. (Current sets must show either a cropped version with the sides cut off or a full version with black bands at top and bottom.) But the most important HDTV attribute is perhaps the much larger field of view it provides. Aided by the multi-channel stereo sound, it puts viewers close to the action, creating a powerful sense of "being there". Watching movies at home, for example, should be just like going to the theater. Similarly, in watching sports, the viewer can not only enjoy the entirety of a baseball diamond, volleyball court or football field, but also have a greater sense of being in the stadium itself. In a football game, for example, the

\textsuperscript{16}Choosing the TV of the Future, Technology Review, April 1989.


\textsuperscript{18}Prospects for the New Generation of Television Systems, Japanese Finance and Industry, 1989 II.
viewer could watch clearly and in detail every aspect of a play as it unfolds instead of having to rely on instant replays of separate tight closeups of the quarterback and the receiver that are used today.

Applications of HDTV
To display full-motion video in real-time, HDTVs must handle enormous information flows and so require immense processing power.\(^\text{19}\) An HDTV receiver thus would be nothing less than a high-speed computer in disguise. With that kind of digital processing capability under its belt, HDTV need not be just another old-fashioned TV set with dazzling pictures. Rather, it can be used to enhance broadcasting in other ways. Some possibilities include: greater diversity in program choices within a given channel; multiple channel audio in multiple languages; on-screen text for the hearing impaired; home printing of text and graphics; and new forms of interactive entertainment.

More important, HDTV is a big step forward in the technological convergence of television, computers and communications products toward systems that can create, manipulate, transmit and display high-quality visual material, including text, data, graphics and full-motion video. For example, one vision of the future home entertainment center is a single system with a high-resolution display that serves as an HDTV, computer, and communications and business link. Connected to a broadband fiber network, HDTV could thus become the key element of a video-based communications infrastructure that will serve as the central nervous system of the information economy of the next century. The possibilities and benefits of HDTV in such a network structure are limitless.

\(^{19}\)The basic HDTV signal carries as much as 1.2 billion bits per second (1.2 Gbps) of picture information. In comparison, a phone conversation uses less than 64 kbps, and a screenful of text that is being changed 60 times per second on a PC needs a data rate of only 15 Mbps. To make transmission to homes practical, digital compression techniques are used to condense the HDTV signal from 1.2 Gbps to 70-80 Mbps. HDTV receivers must then process that signal to create a viewable picture. See U.S. Congress, Office of Technology Assessment, The Big Picture: HDTV & High-Resolution Systems, June 1990.
Beyond information networking, HDTV would also have numerous applications in business, education, medicine, printing, electronic design, movie production, factory automation, publishing, banking, defense systems, and many others. Some of these applications are described in greater detail in Box I.

**HDTV's Rival Systems**

HDTV is not the only advanced television system awaiting commercialization. IDTV (improved-definition television) receivers, which work with existing broadcast standards and offer viewers somewhat better pictures, are already on the market. EDTV (enhanced-definition television) builds on the picture improvements achieved by IDTV and includes a wider screen similar to that promised by HDTV. Though EDTV requires only modest changes in existing standards, it may or may not be introduced in the U.S. - the FCC hasn't been too enthusiastic about it. Box II describes these systems in more detail.

It is important to note that market performance of IDTV and EDTV could have a major impact on how the market for HDTV develops. This topic will be discussed more fully in a subsequent chapter.

**HDTV Standards**

The better HDTV pictures come at a cost. Major changes in production, transmission, and reception standards and equipment are necessary before consumers can watch HDTV in their living rooms. The key attributes of HDTV - higher resolution, wider screen, truer color, and digital sound - require transmission of significantly more information to the receiver than is currently the case. But transmitting the extra information requires a much wider broadcast signal. Compared with the NTSC signal bandwidth of only 6.2 MHz, a full HDTV signal is 32.5 MHz wide.\(^\text{20}\) It would take 5 current channels to

accommodate such an HDTV signal - far too much to be viable. So one essential step to make HDTV transmissions practical is to compress the signal so that it takes up less broadcast spectrum. At the same time, the full bandwidth must be used in the studio production process to preserve program quality. These conflicting constraints have brought about the divergence of production and transmission standards, which almost coincided in the case of NTSC television. Significant developments in each area are reviewed next.

**Production Standards**

Production standards cover specifications for videotaping programs with TV cameras. If these standards differ in various regions, expensive transcoding (conversion) is required for programs produced in one region to be shown in another. This can inhibit international trade in movies and TV programs. Because U.S. movie and TV-program producers are currently the dominant suppliers of video programming to the world, they have promoted a single worldwide production standard to avert this possibility.

Recognizing the need for a standard that allows easy international exchange of programs, SMPTE (Society of Motion Picture and Television Engineers) worked with NHK to refine the Japanese 1125/60/2:1 production format. The modified standard, also known as SMPTE 240M, was optimized to allow easy conversion of HDTV programs to all existing formats.²¹ In May 1986, Japan proposed the 240M standard to the CCIR for worldwide adoption. The Europeans, however, rejected the Japanese proposal despite strong U.S. and Canadian support for the measure. Two months later, the EC created the Eureka-95 program and developed the 1250/50/1:1 system. In May 1990, the two systems were again considered by the CCIR, but neither had enough support to become the global standard. The issue will not be discussed again until the next CCIR session in

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1994 or later. Needless to say, the Europeans have less reason now than ever before to support the Japanese system.

European critics of the Japanese system claim that it does not have enough headroom to convert properly to HD-MAC; the 60-Hz field rate causes problems in converting to 24/25 frames per second film; the system is not of high enough quality to replace film; and its interlaced nature precludes digital manipulation of images. None of these, however, is an obstacle that Japanese could not overcome. The real reason Europe has taken a separate path is the fear that a single global standard based on the Japanese system would allow Japanese manufacturers to make mincemeat of its consumer-electronics industry.

Even within the United States, the 240M standard is controversial. It is accepted "a" standard, not "the" standard. MIT's Professor Schreiber, for example, argues that the NHK system is technically obsolete; its interlaced scanning makes transcoding difficult and expensive; and its acceptance in the U.S. will hurt, not help, the salability of American programs in Europe. NBC and ABC have also opposed the 1125/60 format arguing that conversion from 1125/60 to whatever standard is chosen for the U.S. will introduce unacceptable flaws in the picture. Instead, they believe that a transmission standard should be chosen first that meets U.S. needs. A family of standards can then be established to best meet the national needs of each country.

The international political reality now is that neither the Japanese nor the European system will become the unified global standard. The U.S. had backed the Japanese proposals at the CCIR session in 1986. But with hopes of a single

22Japan is Ready for HDTV, But the Rest of the World Isn't, Electronic Business, Aug. 20, 1990.


global standard all but dead, the U.S. withdrew its support for the Japanese standard in May 1989. Meanwhile, Japanese have doubled their efforts to make their system as the de facto production standard. Studio equipment based on the Japanese system is available from many manufacturers, and several U.S. and foreign companies are currently producing program material in this format. Although it is now unlikely that a single world standard for HDTV production will be adopted, international program exchange standards may yet be developed that allow easy transcoding from one system to another.

**Transmission Standards**

It is virtually certain that there will be three worldwide HDTV transmission standards. Japan is actively promoting its MUSE system, Europe its Eureka-developed HD-MAC system, and the U.S. has yet to decide on a standard. Both MUSE and HD-MAC transmit analog signals via satellites directly to HDTV sets in consumers’ homes, and are incompatible with existing Japanese and European systems. Exhibit 1 summarizes the main features of both systems.

Although several delivery media are well-entrenched in the U.S., terrestrial broadcasting has been the main focus of U.S. HDTV development. This is because terrestrial broadcasting is not only the backbone of the current U.S. television infrastructure, but also the only medium that provides free, universal television to the public. The FCC has ruled that proposed HDTV systems must be compatible with current NTSC-based receivers; and that no additional spectrum outside the existing bands for TV broadcasting would be allocated for HDTV. Because broadcast TV is the most bandwidth-limited medium and faces tougher technical problems than other media, these constraints have made the task of developing a U.S. standard even more difficult. The U.S. approach, however, also entails a crucial advantage. Mandatory compatibility with current TV receivers ensures HDTV program producers that a sizable audience would be available to watch their programs from day one, thereby lowering their downside risk.
The FCC has received 23 proposals for the U.S. standard. After dropouts and consolidations, however, the six systems shown in Exhibit 2 have emerged as final contenders. The FCC has set a rigorous timetable to evaluate these systems and expects to choose a winner by 1993. Though it has decided to test EDTV, the FCC has announced that it will pick an HDTV standard first - in effect scuttling the proposal unless HDTV systems flop.

The proposed HDTV systems represent two fundamentally different approaches to delivering high-definition pictures without sacrificing compatibility with current sets. One approach involves augmenting an NTSC signal by transmitting additional information needed for HDTV. A station would send its current NTSC signal over a 6-MHz channel, and augment that with another 3 or 6 MHz signal broadcast in channels currently left vacant to avoid interference. Since this approach will continue to use, in part, the NTSC system, a major drawback of an augmented system is that the industry would be locked into using a total of 9 or 12 MHz for each station. It also remains to be seen whether the augmentation channel, which transmits at a different frequency, can be decoded well enough to produce sound and pictures that will impress consumers. In the second approach, called simulcasting, each station would transmit two separate signals: one for NTSC receivers and one for HDTV. The HDTV signal would go out on a vacant 6-MHz channel next to a station’s current NTSC frequency. One advantage of simulcasting is that once HDTV became the norm, NTSC channels could either be converted to provide more HDTV stations or be used for something other than television. Because simulcast HDTV signals are not wedded to NTSC, which is highly susceptible to interference and noise, simulcasters also claim better picture quality.

The U.S. standard is also expected to use all-digital transmission. Digital transmissions score over conventional analog systems for several reasons. First, they offer interference-free pictures and allow for easy error-correction - the signal received can be compared with the signal sent. Second, digital signals allow for smaller, less powerful transmitters and home antennas since they
need less power to transmit and are easier to detect at a distance. This will not only help broadcasters and consumers save money, but also reduce the chance of interference with other channels. As a result, stations using the same channel can be operated closer to each other, and broadcasters can squeeze in more channels. Third, a digital transmission system will provide a common network for data, voice and video, and work with all three common distribution media: satellite, cable and terrestrial broadcast. Despite all these advantages, the viability of an all-digital TV still remains to be proven. Digital signals have never been broadcast from an earthbound transmitter, only from a satellite.

One of the most controversial issues in the U.S. standards battle has been whether a single transmission standard should be adopted for all delivery media. Broadcasters, worried about further erosion in their audience share, want a single standard built around terrestrial broadcasting mandated for all media. A single standard, they argue, will ensure compatibility among delivery media and permit consumers to use the same HDTV equipment for all signal sources. With industry-wide compatibility guaranteed, producers, broadcasters, manufacturers and viewers can then move into the HDTV era at minimal risk. Others believe mandating a single standard will force viewers to accept a system that supports the "least common denominator" medium, and prevent each medium from realizing its full potential - in effect depriving viewers of better quality television. Since both cable and DBS can provide better HDTV than broadcast, they contend that each industry should develop the format best suited to expanding and serving its customer base.

Conceivably then, even after the FCC chooses a standard, not all delivery media may rally behind it. DBS, cable and VCRs are not regulated by the FCC in the same ways as broadcast and do not have the same bandwidth constraints. These media can either adopt the 6-MHz broadcast standard, and thus preserve unanimity, or develop their own wide-bandwidth standards, and thus deliver consumers an even better picture. If they choose the latter course, the U.S. will end up with several incompatible standards. Since neither cable
nor DBS would interfere with the broadcast spectrum, each could launch into
HDTV programming without formal FCC approval, and before broadcasters
come on line with the FCC standard. In fact, Hubbard Communications, a DBS
pioneer, plans to start transmitting some HDTV programming in 1993.

It seems, however, that the various delivery media cannot go their own way
without incurring great risk, both for themselves and for HDTV as a whole. No
one would buy three different TV sets to accommodate three different signal
sources. Either a single medium - and a single standard - would find favor, or
all the HDTV media would flop.

Reception Standards
Television receiver standards depend on transmission standards. Since no one
knows which transmission standard(s) will be adopted in the U.S., a great deal
of uncertainty also surrounds HDTV reception standards. Still, several designs
offering varying levels of flexibility and functionality have been proposed for
HDTV receivers. These proposals mainly respond to the current debate over
transmission standards - specifically, whether the U.S. will have augmented or
simulcast transmission system, and whether there will one standard or many
for the different media. Receivers currently conceived can be classified as
closed, multiport, open, or smart. Box III describes each of these designs.

While all proposed designs will work as old-fashioned TV sets, receivers of
greatest interest if HDTV is to become the home information appliance are the
Multiport Receiver and the Open Architecture Receiver (OAR). Multiport
receivers would work with a predetermined set of broadcast standards and
provide limited access for adding voice/data/video communications. OARs follow
the path pioneered by the personal computer industry and would be adaptable
to a much broader range of broadcast standards, personal communications,
computer functions, or other services.
Chapter 2
Market Potential and Market Promotion

HDTV's Market Potential

With its numerous promising applications, HDTV is likely to encompass an enormous range of markets. Though no one has adequately assessed how large the commercial and industrial markets will be, consumer markets alone are forecast to be worth billions of dollars by the year 2000. Three questions are of primary interest when evaluating the market potential of HDTV: When will the market take off? How rapidly will it grow after take-off? And, how large will it eventually become? This section explores these questions by reviewing the results of several market forecasts. Factors that will ultimately determine the answers to these questions are discussed in the next chapter.

Consumer Markets

Although no one has conducted market research to determine the nature of consumer demand, several organizations have projected HDTV markets in the United States. The three most widely discussed forecasts - by EIA\textsuperscript{1}, NTIA\textsuperscript{2} and AEA\textsuperscript{3} - assume that the U.S. market will take off in roughly 1993, 1997, and 2000 respectively. These studies examine the growth patterns in sales of previous successful consumer-electronics products and forecast the growth of HDTV. Specifically, all three forecasts assume that after annual sales reach about one million units (the take-off level), HDTV will replicate the growth pattern of color TV. In addition, they all assume that HDTV will eventually be successful; that IDTV and EDTV will not dampen the market for HDTV, but will instead be part of a natural evolution toward HDTV; that HDTV receivers

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\textsuperscript{1}Electronic Industries Association (EIA), Television Manufacturing in the United States: Economic Contributions - Past, Present and Future, Feb. 1989.

\textsuperscript{2}National Telecommunications and Information Administration (NTIA), Economic Potential of Advanced Television Products, April 7, 1988.

\textsuperscript{3}American Electronics Association (AEA), High Definition Television (HDTV): Economic Analysis of Impact, Nov. 1988.
will be available to consumers in the early 1990s; and, that HDTV broadcasts compatible with NTSC receivers will begin soon thereafter.\(^4\)

**EIA Forecast:** The EIA predicts that HDTV will be first commercialized as a high-end product. With significant sales beginning in 1993, HDTV receivers are forecast to completely replace 30-inch and larger NTSC sets by 1998. The EIA estimates that 13.1 million of the 40.2 million TVs sold in the U.S. in 2003 will be HDTVs, and that HDTV sales will have a retail value of $11.8 billion, 71.1% of all color TV sales.\(^5\) Furthermore, retail sales of color TVs in 2003 will be $16.6 billion with HDTV, but only $12 billion if the market continued without HDTV. Household penetration of HDTV receivers will reach 10% in 1996, and exceed 25% by the end of the 20th century.

**NTIA Forecast:** NTIA considers HDTV receivers and VCRs as necessary complements, or tied products, for the first 5 years after take-off with equal unit sales in each year. After 2002 when both products achieve about 25% household penetration, NTIA assumes that sufficient programming may be available from other media to begin to sever the VCR/receiver bond. Beginning in 2003, VCR unit sales are thus assumed to be 80% of receiver sales for the first 3 years, and 60% of receiver sales for the next 3 years. For the year 2008, NTIA forecasts sales of $7.5 to $14.9 billion for 18.6 million receivers and $3.3 to $6.7 billion for 11.2 million VCRs. Projected household penetration in 2008 is 93.9% for receivers and 71.1% for VCRs.

**AEA Forecast:** AEA predicts that noticeable consumer demand for HDTV products will emerge in 1996 when HDTV broadcasts are assumed to start.

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\(^4\)The assumption that consumer sales of HDTV will begin in the early 1990s is outdated. It is now obvious that the FCC will not select a transmission standard before 1993 at the earliest. Because manufacturers will require 18 to 24 months to commence production after a standard is set, a more realistic date for the U.S. introduction of HDTV is 1995.

\(^5\)All sales given here are in 1988 dollars. EIA values were discounted to 1988 dollars at 3.5% annual inflation rate from the EIA estimate of $19.7 billion in 2003. NTIA and AEA sales figures are assumed to be already in 1988 dollars as they cite no inflation rates.
(Small sales of Japanese receivers and VCRs are forecast prior to 1996, but AEA assumes that those will be mainly to professional users.) The U.S. market in 2010 is forecast to be worth $6.6 billion for 11 million receivers and $4.3 billion for 9 million VCRs. AEA also projects the worldwide market for HDTV receivers and VCRs (Exhibit 3). Worldwide receiver sales in 2010 are expected to be 30 million units worth $18 billion at retail, while the VCR market could absorb 22.2 million units, adding another $10.5 billion.

Exhibits 4, 5 and 6 compare the three forecasts in terms of unit sales, market value, and household penetration. Exhibit 7 gives a comparative summary of the forecasts along several important dimensions. This comparison clearly shows that the three studies differ principally with respect to the speed at which HDTV will become a commercial success. Most bullish is the EIA. Most conservative is the AEA, which projects a smaller market that also takes off after a lag of several years. The actual timing will be determined, in part, by the pace of technological progress, which is very difficult to predict accurately. It is worth noting that while these forecasts differ on market size and timing, they all agree that the HDTV consumer market alone is potentially very large, and that HDTV will be a major new part of consumer electronics. For comparison, the overall U.S. consumer-electronics market in 1990 was worth $32.9 billion in factory sales, or more than $44 billion at retail.6

The forecasts share two critical assumptions - that HDTV will be a success with consumers, and that the market will grow rapidly. None of the forecasts has a scenario for true failure, even though such products are frequently launched. Many new consumer products are not major successes. Many fail outright, while others take decades to become a major commercial success. Some fail as a result of bad design or marketing, while others fail because of demographic or other factors. In all forecasts, HDTV receivers are predicted not only to be successes, but to be one of the most successful consumer-electronics

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products. Some believe that these forecasts are near the high end of the potential range of market size and overstate how rapidly the market will actually grow. Since color TV and VCRs have been among the most successful consumer-electronics products, critics argue that using their history of success as a pattern for HDTV's market growth is misleading.\(^7\) Exhibit 8 compares the projected growth of HDTV sets with the actual growth of current TV products.

**Non-Consumer Markets**

The market estimates given above are for home entertainment alone. Commercial and industrial markets for HDTV may be more important. The major reason non-consumer markets have been ignored by these three studies and others is that no one has yet adequately explored this subject. The Japanese MPT, for example, estimates that sales of consumer equipment will be less than 60 percent of HDTV's total sales potential.\(^8\)

One illustrative example of the potential size of the non-consumer markets is the recently awarded FAA contract to Sony for high-resolution displays to modernize the U.S. air traffic control system. This contract will be for up to ten thousand 2000-line monitors, at a cost of $40,000 apiece. The total amount to be spent for these monitors and related electronics has been estimated to exceed $1 billion over the lifetime of the contract.\(^9\) Another example is Ford's $10 million purchase of Sony HDTV equipment that the company is using to shorten the design cycle for new cars.\(^{10}\)

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\(^8\) Television Makers Are Dreaming of a Wide Crispness, Business Week, Dec. 21, 1987.


\(^{10}\) Japan's HDTV: What's Wrong With This Picture?, Business Week, April 1, 1991.
**Japanese and European Markets**

Critics have questioned the U.S. forecasts claiming that they are too optimistic. The Japanese, however, are predicting a much bigger market and a much faster rate of growth for HDTV. The MPT predicts that the Japanese market will take off in 1993, and that television-related HDTV sales in Japan will be 900 billion yen ($6.9 billion) in 1995 and 3.4 trillion yen ($26 billion) in 2000. Between 1990 and 2000, HDTV-related sales in Japan will total a staggering 14.5 trillion yen ($112 billion), according to MPT.\(^{11}\) Projected household penetration in 2000 is 50% for receivers, 20% for VCRs and 5% for video disc players.\(^{12}\) The MITI forecast contains estimates of a similar magnitude. The figures in MPT and MITI forecasts are striking since they are far more optimistic than any of the U.S. forecasts. AEA, for example, estimates the Japanese receiver and VCR markets to be worth only $1.6 billion in 1995, $3.7 billion in 2000, $6.7 billion in 2005 and $4.2 billion in 2010.

BIS Mackintosh, a London-based market research firm, predicts that annual sales of HDTV receivers in Europe will reach 1 million units by 1997 and 3.5 million units by 2000.\(^{13}\) AEA puts receiver sales in Europe at 1 million units worth $1.5 billion in 2000, and 8.5 million units worth $5.1 billion in 2010. VCR sales are estimated as .8 million units in 2000 and 5 million units in 2010, valued at $720 million and $2.4 billion respectively.

**Market Development and Promotion**

Despite the vast commercial potential of HDTV, getting it into America's living rooms will not be easy. Getting the U.S. color TV market off the ground in the early 1960s took RCA 20 years and $3 billion (1988 dollars).\(^{14}\) Due to the lack

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\(^{11}\)Japanese Ministry of Posts and Telecommunications (MPT), HDTV Promotion Committee.


of an installed base during the early years, market promotion of HDTV will be essential to provide consumers the opportunity to observe a receiver outside of dealer showrooms. Market promotion plays a key role in the success of new products, since it provides consumers valuable product information, and fuels the desire of conservative buyers to follow the pioneers.

While the U.S. is still caught up in the standard-setting process, development of HDTV markets is well underway in Japan and Europe. Both have launched wide-ranging and vigorous programs to make HDTV programming available and to promote the purchase of HDTV hardware. Their efforts are described here to illustrate the nature of promotional programs that will be necessary if HDTV is to become a commercial success in the U.S. any time soon.

**Japan**

Japan has a carefully orchestrated plan for building an HDTV consumer market. The MPT first embarked on heavy promotion of HDTV to the Japanese public during the 1988 Seoul Olympics. NHK broadcast 73 hours of this event over a 17-day period,\(^{15}\) which people could watch on 208 HDTV sets at 81 locations.\(^{16}\) In June 1989, NHK began broadcasting HDTV programs via satellite for one hour a day. About 150 HDTV viewing sites have been set up countrywide to enable the public to see HDTV first hand.\(^{17}\) NHK increased the HDTV broadcasts to 8 hours a day in November 1991.

To stimulate market demand, MITI and MPT have established a number of promotional committees and councils. Working closely with the industry, these groups are staging showcase applications of HDTV at public events. MPT organized the 31-member Hi-Vision Promotion Council in 1987 to put interested broadcasters, manufacturers and customers in touch with one


another. Each year the council coordinates a variety of promotional events during the Hi-Vision Week in November and holds HDTV demonstrations at fairs throughout Japan. The powerful MITI has also taken an active role in promoting HDTV, especially in industrial markets. Its Hi-Vision Promotion Center helps set standards for industrial HDTV equipment and surveys new uses in the industrial sector.

The MPT Hi-Vision City and MITI Hi-Vision Community programs are perhaps the more ambitious of these market development efforts. These projects are intended to demonstrate Hi-Vision hardware and software, stimulate the purchase and use of Hi-Vision equipment, and provide a test market for Hi-Vision applications. The $96 million MPT Hi-Vision City program selected 18 cities in March 1989 to receive support in purchasing and using Hi-Vision equipment. These cities are pilot projects to study uses for HDTV, including developing video and graphics databases for museums, schools and other public uses, and to use leading-edge information technologies and services.\(^{18}\)

Recognizing that HDTV will not be purchased unless programming is available, MPT and MITI have established leasing companies. Nippon Hi-Vision was formed in April 1989 by the MPT, NHK and 40 private companies to purchase and then lease HDTV equipment to broadcasters.\(^{19}\) In June 1990, MITI established the Hi-Vision Community Program to produce HDTV programming, to set up markets for leasing HDTV hardware and software, and to consult with potential users; 82 companies have invested more than $13 million in this project.\(^{20}\) These leasing companies reduce risks for both manufacturers and users of HDTV equipment - by guaranteeing sales for

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\(^{18}\)Japan is Ready for HDTV, But the Rest of the World Isn’t, Electronic Business, Aug. 20, 1990.


\(^{20}\)Japan is Ready for HDTV, But the Rest of the World Isn’t, Electronic Business, Aug. 20, 1990.
producers, providing equipment to users at low cost and ensuring that movies and TV programs of HDTV-quality are produced for viewers to watch.

All this government support gives Japan's electronics firms the sense of security they need to bring new products to the market. As a result, a full complement of Hi-Vision reception, transmission and production equipment is available from manufacturers such as Hitachi, Matsushita, NEC, Pioneer, Sanyo, Sony and Toshiba. These firms have begun national sales campaigns to market the first HDTVs. The consumer market may be still years off, but Hi-Vision is already becoming well entrenched in a number of commercial and industrial markets. Hundreds of department stores and municipalities have purchased $100,000-plus projection systems to show programs from promotional spots to sporting events. Construction companies use HDTV to simulate placement of proposed projects, and universities and training programs use HDTV to broadcast lectures or lab exercises to class rooms around the nation.21 The Japanese consumer market should not be far behind, especially as prices tumble in response to emerging non-broadcast markets.

NHK and manufacturers who have committed millions of dollars in R&D, production capacity and promotional efforts to develop Hi-Vision are using similar tactics to push Hi-Vision overseas. To keep abreast of customers' needs and the uncertain standards scene, a number of Japanese firms, including Matsushita, Sony, Toshiba and Hitachi, have opened R&D divisions in the U.S.22 Since Hi-Vision is currently the only practical, commercially available HDTV system in the world, Japanese firms are working hard to establish their technology as a de facto standard. Columbia Pictures' Culver City studio, for example, is a perfect showcase for HDTV technology, embodied in Sony products. To sell Hollywood on the wonders of HDTV electronic imaging, Sony

21Japan is Ready for HDTV, But the Rest of the World Isn’t, Electronic Business, Aug. 20, 1990.

22Japan is Ready for HDTV, But the Rest of the World Isn’t, Electronic Business, Aug. 20, 1990.
has set up a production center at Columbia. Producers, directors, and special-effects supervisors from any studio are free to come and experiment.\textsuperscript{23}

With the foreign consumer markets stalled by standards battles, Japan's electronics giants such as Sony and Matsushita have doubled their efforts to exploit commercial and industrial markets. A number of non-broadcast users - in moviemaking, computer-aided design and manufacturing, electronic publishing and a host of other sectors - have already purchased HDTV equipment. Ford, for example, has acquired more than 30 Sony systems for CAD/CAM, complete with car-sized displays, to design cars, engines and other auto subsystems. Through such sales to industrial users, Japanese manufacturers intend to achieve economies of scale and lower prices that will be necessary before consumers will buy HDTVs.

\textbf{Europe}

Europe plans to rebuild its entire broadcasting infrastructure around HDTV through a program called "television without frontiers" that will create a new, high-definition, satellite-based system. Applicants for the new satellite channels must sign on to a program that moves in three stages to a true HDTV system by 1992.\textsuperscript{24} Coverage of the 1992 Summer Olympics in Spain is planned as the kick-off for HDTV broadcasting in Europe. One thousand receivers will be scattered throughout Europe for public viewing of these broadcasts.\textsuperscript{25}

The European industry and governments have spent several hundred million dollars on development of the European high-definition technology. Using Eureka funding, manufacturers are working closely with state broadcasters, such as Britain's BBC and Italy's RAI, to produce HDTV equipment and

\textsuperscript{23}Will Sony Make It In Hollywood?, Fortune, Sept. 9, 1991.

\textsuperscript{24}American Electronics Association, Testimony before Senate Committee on Governmental Affairs, S. Hrg. 101-226, Aug. 1, 1989.

programming. Europe’s broadcasters are learning to produce HDTV programs on mobile equipment vans supplied by Eureka-95. Costing between $1.7 million and $4 million each, the vans are loaded with prototype equipment for recording and post-production work.\textsuperscript{26}

The EC has targeted HDTV as a major priority of the new unified Europe and has established the European Company for Research and Promotion of HDTV. Owned jointly by the EC, and individual governments and electronics firms, the company is coordinating HDTV research, building HDTV studios and promoting HDTV demonstrations. The EC has also created EEIG (European Economic Interest Grouping) consisting of manufacturers, program producers, broadcasters and governments. EEIG’s main goal is to facilitate equipment trials and raise awareness of European HDTV technology among potential users. It is providing equipment and technical know-how for such users.\textsuperscript{27}

Chapter 3
Major Issues in Commercializing HDTV

HDTV is a substitute for current TV sets rather than a unique, entirely new product. Many of the issues that will determine the eventual fate of HDTV are therefore similar to those faced by the products it seeks to replace. Appendix B looks at the histories of current TV sets and identifies factors that influenced their market penetration. The problems faced by color TV are especially relevant since color TV was in the same position in the mid-1950s as HDTV is today: an improved technology attempting to replace an existing technology. Exhibit 8 compares the projected growth of HDTV receivers with the actual growth of existing TV products.

Product histories show that most new products do not become overnight successes. They instead go through three distinct stages of growth. Box IV describes these stages and the market forces that come into play and influence the market development of new products during each stage. Though it is impossible to predict the precise course that HDTV will take, the market penetration of HDTV will depend on a variety of factors, including: the prices of HDTV and closely related products (substitutes, complements); the availability of movies and programs; the consumer response to IDTV, EDTV and HDTV; the policies and standards chosen by the government; and the state of the economy, among others.

Receiver Prices
Prices will have a big influence on the rate of penetration of HDTV. The relationship between product prices and rate of household penetration is one of mutual interaction. Cause and effect goes in both directions. Declining prices increase sales and thus speed up household penetration. Higher penetration, in turn, increases product exposure and fuels the purchase incentive of still
skeptical consumers. As sales grow, manufacturing costs and prices fall further due to economies of scale and learning curve effects.

While no one knows how much consumers are willing to pay for better pictures, many believe that high receiver prices will be a major impediment to rapid market penetration of HDTV. Exhibit 9 shows the price assumptions of market forecasts discussed in chapter 2. These forecasts assume that an HDTV receiver will initially cost between $2,500 and $4,000, and that prices will decline fairly rapidly thereafter. The fact, however, is that HDTV sets in Japan still cost about $28,000 apiece and consumers are not showing much interest.¹

Since consumers will not pay a fortune for a TV set no matter how good the picture is, prices must come down sharply if high sales volumes are to be achieved. To be acceptable, an HDTV receiver will have to cost no more than 3 or 4 times the price of an NTSC color set. That was the multiple at which color TV sales took off in the 1960s: the yearly demand for color TV grew from 438,000 units in 1962 to over 5 million units in 1966 while color TV prices remained roughly constant at $1300 and the differential between B&W sets and color sets was $840 in 1988 dollars.² By that reckoning, then, HDTV sets will have to come down to around $1,500 before sales can take off. The NTIA study, in fact, states that unless prices fall substantially below $1,500, the projected penetration rates are very likely unattainable.

The history of consumer-electronics gives every reason to expect that HDTV prices will indeed come down as production builds up and as technological advances lower costs. Exhibit 10 shows the decline in prices of TV receivers since 1950. The actual behavior of B&W TV, color TV and VCR retail prices is depicted in Exhibits 11, 12 and 13 respectively. While the CPI has increased by

¹Poor Man's HDTV?, Business Week, June 24, 1991.
456% since 1950, the prices of TV receivers have actually declined by over 54 percent (Exhibit 10). In real terms then, the price of an average TV receiver in 1990 was just 8.2% of what it was in 1950. Given the current pace of advances in component and process technologies, this pattern should in fact accelerate with HDTV. One can easily imagine numerous developments which will affect product design, costs, quality and price - all of which will shape the willingness of consumers to replace their NTSC sets with HDTV.

The issue of greatest interest, however, is not that HDTV prices will fall over time, but how quickly they will fall in the near-term. According to Stanford Resources, the price of an HDTV receiver will come down to $7,549 in 1995 and $1,911 by 2005. There are four major reasons why HDTV prices should not only decline precipitously, but they ought to fall at a rate faster than the rate of decline for any previous consumer-electronics product: large economies of scale and scope, keen competition, and rapid technological advances.

**Economies of Scale**

The key components of an HDTV receiver - semiconductors (especially DRAMs and DSPs), displays, magnetic and optical storage - are also the key components in today’s advanced PCs and workstations. As a result, they are already widely used in computer, telecommunications and many other industries. It is estimated that variable costs would account for about 75% of the market price of an HDTV receiver and that material costs will be a large portion of this. As large new demand from HDTV further increases the production volumes of these components, their costs will fall due to economies of scale and learning curve effects.

The projected HDTV consumption of semiconductors and displays - which account for about 10% and 25% of the retail price of an HDTV receiver.

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3Japan is Ready for HDTV, But the Rest of the World Isn’t, Electronic Business, Aug. 20, 1990.

respectively⁶ - is shown in Exhibits 14 and 15. Using assumptions of the market forecasts discussed earlier, the OTA estimates that world demand for DSPs and other processing chips for HDTV alone in 2003 could be as much as 10 times total world production of all logic chips in 1987. Similarly, the use of DRAMs in HDTVs in 2003 could be 5 times the total 1987 world demand for all DRAM applications, and if active-matrix LCDs became the display of choice, screen production for HDTV would be nearly 6,000 times total world production of AM/LCD screens in 1987. If strong commercial markets for HDTV also develop, as predicted by the Japanese MPT, then chip demand could be twice the projections above. Including production and broadcasting equipment sales could increase these projections by another 10 to 15 percent.⁶

It is important to note that these projections do not even consider the escalating demand for these components in computers, telecommunications and other markets. Depending on the growth of these other markets, the demand from HDTV may or may not be a significant fraction of the total component output in 2003. It is clear, however, that HDTV alone would almost certainly have a strong impact on the cost of these components. Producing a particular 16-bit chip for the large CD-player market, for example, drove its price from $75 each to just $3.75, while the price of a less complicated 14-bit chip that did not benefit from such a large market demand stayed at $60.⁷

**Economies of Scope**
Because HDTV is a fundamental new imaging technology, it will also have numerous non-consumer applications in many different sectors of the economy. In addition, virtually all of the HDTV component technologies are themselves

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⁶Electronic Industries Association, Consumer Electronics, HDTV and the Competitiveness of the U.S. Economy, Feb. 1, 1989. Semiconductors and displays will account for a much higher fraction of factory costs, typically 20% and 50% or more, respectively.


generic and have myriad other applications that are driving their development. There is no question that all of these technologies will be increasingly used in still unforeseen applications in the future.

The markets for HDTV flat-panel technology, for example, may in total exceed even the HDTV consumer market. Flat panels may be used in automotive displays, laptop computers, engineering workstations, medical imaging, video games, industrial imaging, CAD/CAM, graphics and video simulators, scientific instrumentation, industrial controls, radar, air traffic control, navigation, telecommunications, personnel training, military command and control, etc. All of these potential flat-panel markets would also require large quantities of DRAMs and other electronics to support the flat-panel displays.\(^8\)

**Competition**

Competition in HDTV is expected to be fierce. Besides promising a potentially huge market, HDTV represents a major technological change and is likely to attract new entrants into consumer electronics. An important factor driving competition is the potential linkages between HDTV technologies and other industrial sectors. Many argue that the know-how to make displays and other components gained from a presence in the HDTV market will give a firm significant advantages in producing related components and systems for many other markets. As a result, some predict that the end reward for those who design, manufacture and sell to the HDTV market will be dominance of computers and telecommunications.\(^9\) It is precisely the expectation that rewards will be great in consumer HDTV that has set two headstrong industries - computer and consumer electronics - on a collision course.

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\(^8\) Photonics Technology, Letter to Senate Committee on Governmental Affairs, Aug. 24, 1989.

**Technological Progress**

The core technologies of HDTV are the same as those used in advanced computers and telecommunications devices. The technological breakthroughs affecting components, product design and production processes in the computer industry are occurring at breakneck speed:

- The industry has been doubling the number of components on a chip every year for more than 30 years. As a result, the cost per circuit has fallen more than a millionfold. Today a single microprocessor concentrates within it the power of the first Cray supercomputer.\(^{10}\)

- The $2,665 that bought a bare-bone IBM PC in 1981 today buys a computer with 35 times the processing power, 1,200 times the disk capacity, a high quality color monitor, and more.\(^{11}\)

- Over the past 10 years, the capacity of DRAMs has increased by 250 times while the cost per unit memory has decreased nearly 100 times.\(^{12}\) HDTV signal processing chips that would have cost $20,000 to $30,000 as recently as 10 years ago cost only $100 to $200 per receiver today.\(^{13}\)

Such rapid technological advances and cost reductions will likely make HDTVs affordable in the not-too-distant future. In fact, it appears that HDTV is pushing the limits of some technologies even faster than are computers or telecom systems.\(^{14}\) For example, at the 1989 International Solid-State Circuits Conference, some of the fastest DSPs ever developed were specifically designed for HDTV. Similarly, HDTV research at Sarnoff Labs has led to the

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\(^{10}\)Telecommunications in the 1990s, Business Horizons, Jan-Feb. 1990.


\(^{14}\)HDTVs must handle huge information flows and computational speeds in order to display high-resolution pictures in real time. An uncompressed HDTV signal contains about 1.2 billion bits per second (1.2 Gbps) of information. In comparison, today's workstations hit peak speeds internally of about 0.5 Gbps. To convert the compressed signal into viewable pictures, an HDTV receiver has to perform as many as 2 to 3 billion mathematical operations per second. HDTVs can do this at relatively low cost by using DSPs dedicated to specialized tasks. Similarly, access times needed for HDTV memory chips must be about 20 nanoseconds (ns). Today's fastest DRAMs have typical access times of 60 to 80 ns.
development of a video-supercomputer capable of an information flow rate of 1.4 Gbps and computational speed of 1.4 trillion mathematical operations per second at a cost of less than one-tenth that of other supercomputers. Manufacturers are also achieving breakthroughs in memory and storage technologies. Matsushita's 8 Mb Video RAM, designed specifically for HDTV, has a serial access time of 20 ns, 1.5 times faster than current VRAMs. Sony has developed a studio VCR that has a recording speed of 1.2 Gbps - five times faster than the previous record, and Matsushita has succeeded in storing 2.6 GB of video information on a single 12-inch optical disk.\textsuperscript{16}

Efforts to reduce the number of chips needed can already be seen in HDTV. NEC reduced the number of chips in its IDTV from 1,800 to 30.\textsuperscript{16} An early prototype of the Japanese MUSE HDTV decoder had 2,000 chips on 50 printed circuit boards (PCBs). In contrast, the MUSE decoder unveiled in June 1989 had only 96 chips on just 2 PCBs. The result is expected to reduce the weight of a smaller HDTV receiver from 50 kilograms to 1.5 kilograms. Japanese hope to further reduce the number of chips on each board to 3 or 4.\textsuperscript{17} It won't be long before nearly all of the required memory and DSP for an HDTV might be combined on a single chip.

Currently, packaging/interconnecting (P/I), assembling and testing account for about 30\% to 50\% of the total cost of a complex electronic system, and limitations of P/I technologies are a principal barrier to increasing chip densities, lowering costs and improving performance. Mass application of chip-on-glass technology soon promises to bring major improvements, however. The Japanese MITI and Key Technology Center HDTV flat-panel consortium, which is working feverishly to develop new lithography and thin-film technologies for


\textsuperscript{16}NEC Takes An Early Lead in Improved-Definition TV, Electronics, Dec. 17, 1987.

\textsuperscript{17}American Electronics Association, Testimony before Senate Committee on Governmental Affairs, S. Hrg. 101-226, Aug. 1, 1989.
large-area flat-panel displays by 1996, intends to use those technologies along with improved and lower cost chip-on-glass technology to increase PCB densities. Chip-on-glass technology mounts bare ICs directly on lithographically printed glass substrates. Lithographic printing can provide 10 times the wiring density attainable with the copper-epoxy PCBs. A PCB with 40 layers of copper-epoxy interconnect might be replaced with a lithographically printed glass substrate with just 2 layers of interconnect. This will allow higher speeds, reduce size and weight, and cut costs in both design and production.\textsuperscript{18}

One key component that is likely to keep HDTV prices high in the near-term is the picture tube. The benefits of HDTV become apparent only on large screens, but making CRTs larger than 40-inches and with HDTV’s Cinemascope shape is exceedingly expensive. All technologies for producing flat-panel displays are inherently trickier and, some say, unlikely to prove any cheaper. A flat-panel TV monitor, with just a 14-inch screen, currently costs $75,000. The lowest estimate for a 32-inch flat-panel monitor in five years’ time is $12,000.\textsuperscript{19} Others argue that development of flat-panel displays is likely to result in substantial price reductions in HDTV. Above 40 inches, industry experts predict that flat-panel technologies will come out ahead on price.\textsuperscript{20}

**Availability of Programming**

Low price is certainly one of the important preconditions for rapid market penetration of HDTV receivers, but the most important factor, it seems, will be the availability of HDTV programs. Television is driven by programming, not by fancy technology. Without programs to watch, nobody will buy an HDTV receiver no matter how dazzling its picture quality.

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\textsuperscript{20}Bigger, Wider, Flatter, Brighter: The Key To Making It In HDTV, Business Week, Feb. 26, 1990.
The growth patterns of consumer-electronics products clearly show that the compelling motivation for the purchase of hardware has always been software. B&W TV sales, for example, grew rapidly in part because TV stations were built quickly in the key markets (Exhibit 11). In contrast, sales of color TV languished for many years primarily because few color programs were broadcast for consumers to watch. As the share of prime-time hours in color went from 20% to 100% between 1963 and 1966, annual sales of color TV went from 747,000 units to over 5 million units (Exhibit 12). Similarly, VCR sales took off when videotape rental stores offering a wide selection of movies became common (Exhibit 13). And there is no question that DAT - with its CD-like sound without a trace of crackle or hiss - could quickly render the conventional cassette deck obsolete. But it is stuck on the manufacturer's shelf largely because very few music titles are available.

It is also worth noting that while Sony's Betamax VCR was widely regarded as technologically superior to VHS, lack of software was the key reason for its eventual death. The fight between VHS and Betamax ended when video rental stores around the world decided that they could no longer afford to carry two lines of the same titles, one for each format. They opted for VHS and that helped speed the demise of Betamax.

So, it appears that the winner in the HDTV stakes will not be the hardware but software. The growth of HDTV will depend a great deal on the availability, quality and diversity of compatible programming. The investment decisions made by program producers and distribution media will be critical to fuel consumers' desire to purchase HDTV receivers, and vice versa. Any delay in programming availability, or a perception among consumers that HDTV programs are not substantially different from current programming, would delay consumer interest in switching to HDTV. Most consumers probably prefer watching better visual images, but they may be unwilling to absorb the expense of an HDTV receiver on that basis alone, particularly if they are restricted in their program choices.
On first thought it appears that there are major obstacles to HDTV programming becoming available any time soon after HDTV's introduction. Program producers and distribution media face high costs and substantial risks in switching to HDTV. Experts say it will cost broadcasters as much as $15 million to equip a typical TV station for HDTV.\(^2\) Similarly, HDTV production equipment is currently very expensive. But a closer analysis shows that powerful economic and market forces are likely to ensure availability of HDTV programming fairly quickly. First, HDTV is an efficient, effective and economical means of producing not just TV programs but also motion pictures. Second, the advent of HDTV has triggered a power struggle among broadcasters, cable operators, DBS hopefuls and even the telephone companies, who all want a piece of the action - at the expense of their rivals. These issues will be explored in detail in chapter 5.

**Government Policies and Standards**

The outcome of the standards race currently underway could have a powerful influence on the way the HDTV market develops. While standards do not create an industry, they allow it to develop. Standards minimize confusion, ensure compatibility and expedite consumer acceptance of a product. In addition, standards allow manufacturers to increase production efficiency by producing in large volumes for a uniform market. Ultimately, broadcasters, program producers, and manufacturers must take considerable risks in order to provide pictures that consumers will want to see. Clear and consistent government policies, particularly those of the FCC, are essential if potential investors are to take these risks.

The FCC plans to set only the terrestrial broadcast standard. It intends to permit the alternative media - cable, DBS, fiber and VCRs - to use whatever transmission standards they desire. This is extremely risky. According to MIT's

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\(^2\)Poor Man's HDTV?, Business Week, June 24, 1991.
Prof. Schreiber, "you have to believe in magic to think that these alternative media will coordinate with one standard." So if incompatibilities arise between different media or if there is confusion in implementing the standards, consumers may hesitate in purchasing an expensive HDTV receiver that has only limited applicability. Many program producers, broadcasters and manufacturers may also hold back from HDTV until the compatibility issues are settled. This could significantly slow HDTV's market development. And if a number of incompatible HDTV receivers appear on the market, HDTV will be struck a serious, if not fatal, blow.

If the FCC allows the standards to improve incrementally (which may happen if all HDTV proposals flop), with IDTV, EDTV and other gradual improvements in performance, then consumers may decide to stop short of HDTV, depending on price and viewing preferences. If the standards do not include intermediate enhancements, but move directly to HDTV, then the market may or may not develop depending on consumers' perceptions of the product's usefulness. Given the choice to view the same picture in both NTSC and HDTV simultaneously, consumers may decide that better quality of HDTV for the same programming is not worth the extra cost. However, if NTSC were phased out over a number of years in order to make better use of the broadcast spectrum, then consumers would have no choice but to buy HDTVs.

Failure of the FCC to adopt an HDTV standard might well result in the emergence of a de facto standard, or worse, multiple inconsistent standards. For example, a de facto standard might develop that interfaces well with cable or DBS, because those media might be able to offer HDTV before broadcasters. Multiple inconsistent standards would fragment the market and thus delay or prevent HDTV's growth. For example, after unsuccessful attempts to set AM stereo radio standards, the FCC left the decision to the marketplace in 1982. Several incompatible systems then began to be adopted. This increased consumer, broadcaster and manufacturer confusion. As a result, AM stereo's growth has been dismal.
And even if, unlike AM stereo, HDTV broadcasting does eventually take hold even with multiple standards, the switch would still prove costly for both consumers and broadcasters alike. Market fragmentation would result in higher equipment costs and wasteful purchases for those who opt to purchase equipment based on an ultimately unsuccessful standard. Given the expense and uncertainty surrounding HDTV, broadcasters, manufacturers, consumers and perhaps even alternative media will more readily invest in HDTV if there is a single federally-mandated HDTV broadcast standard.

Intermedia compatibility also holds the promise of providing each viewer with the widest choice of program sources and each programmer with the largest potential audience, and of reducing the cost of HDTV equipment through economies of scale. The FCC recognizes these benefits, but is concerned that mandating compatibility carries the risk of retarding the alternative media, and asserts that there are market and institutional forces which will ensure exchangeability of programs among the various media.

It is also important that the FCC settle on a standard fairly quickly. The more the industry delays the introduction of HDTV, the slower will be its consumer acceptance. For example, the software industry's delay in agreeing on a copy-protection scheme has already made DAT yesterday's news. There is a growing feeling that DAT may now have missed the boat. Industry folklore suggests that, to become a hit product, any new product has to be grabbed by hard-core enthusiasts while it is still a novelty and then raved about in the press. Mass production, distribution and advertising do the rest. For novelty seekers, DAT's arrival was delayed so long that it became yesterday's news before hitting the streets. Besides, DAT now has competition. Philips's recently introduced DCC (digital compact cassette) is a formidable rival.
Consumer Perceptions of HDTV

It would seem obvious that nearly all viewers would like a sharper picture with a wider screen and better audio. The actual evidence in this regard so far, however, is mixed. Many consumers watch TV without the benefit of either rooftop antennas or cable, relying instead on rabbit ears or internal antennas. Many viewers still watch B&W TVs, at least as a second set - over 1.4 million B&W TVs were sold in the U.S. in 1990. On the other hand, cable TV has now penetrated almost 60% of the 93 million TV households - both for the higher quality of picture it provides and especially for the greater variety of programs it offers. Further, large-screen TVs are rapidly growing in popularity despite their high cost. The market for 25-inch and larger screens increased from 2.8 million in 1982 to 5.5 million in 1987.22

HDTV market research is similarly ambiguous. A study by MIT, for example, gauged consumer response to HDTV in comparison with studio-quality NTSC on today's relatively small displays. The study found that two-thirds of the viewers preferred HDTV. In one instance, however, 60 percent of viewers watching a football game preferred NTSC over HDTV when seated about 10 feet (the ideal viewing distance for NTSC) from 18-inch sets.23 But when seated 3 feet (the ideal distance for viewing HDTV) from 28-inch monitors, 75 percent of viewers preferred watching the 1984 Olympics on HDTV rather than on NTSC. Given these swings in viewer preference in response to screen size, viewing distance and program content, the study concluded that "the preference for HDTV is highly conditional and context dependent... that demand for HDTV will be highly interdependent on the development of inexpensive large-format displays."24

22Electronic Industries Association, Electronic Market Data Book, various years.
23Since the additional detail provided by HDTV would be lost on a small-screen set when viewed from a distance, viewers naturally had little preference for HDTV.
It is important to note that the pictures shown in these tests were studio quality. For NTSC, this is a big improvement over what viewers normally see at home: the quality of NTSC is often poor due to transmission degradations.

Because the MIT study yielded a preference for HDTV, but not a dramatic one, HDTV critics question the claim that HDTV is a technology as revolutionary as color TV was in the 1950s. Proponents respond that such critics have simply misunderstood the findings of the study. What these tests really show is that to fully appreciate 17" DTV larger and brighter displays are needed. Sony, for example, believes that a 72-inch screen is required to portray the full capability of the Japanese 1125/60 system.

Proponents point to the growing market share of large-screen TVs as evidence that consumers will go for the big-screen HDTV receivers. TVs with tubes 19 inches and under represented virtually all sales of tabletop and portable receivers in 1980, but this share has dropped substantially in recent years and the share of large-screen TVs - those with tubes 25 inches and over - has increased quite rapidly. Big-screen TVs with 27-inch to 35-inch tubes was a growth area in 1990 despite the fact that overall color TV sales declined. Also, receivers with larger tubes were not widely available until recently. The trend to jumbo TVs has also caught on in Japan, where 50% of the sets now being sold have screens bigger than 32 inches.

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Product Design, Quality and Functionality

As indicated by the number of proposed designs, the specifications for HDTV receivers are currently pretty much up in the air. The success of HDTV will depend on how it is brought into the market and how fast the manufacturers produce a product that consumers want. Product histories indicate that consumers not only want products that are easy to use, but sometimes place emphasis on features unforeseen by the industry experts. In the case of VCR, for example, ten years of unsuccessful consumer-oriented VCRs preceded the model that became an overnight success. The features that have made today's VCRs so popular were not apparent or even possible in the period when firms decided to develop a consumer VCR.\(^{30}\)

Two things seem to be important under product quality: reliability and performance. Though poor reliability of both B&W and color TV sets impeded their consumer acceptance for several years, reliability of HDTV receivers is unlikely to become an issue. Not only major improvements have been achieved in production technologies since the 1970s, but manufacturers that now specialize in consumer electronics put enormous effort into making their products reliable enough to outlast the most hamfisted of users for years.

To see how good the picture quality of HDTV has to be to attract consumers, one just needs to look at the most recent products in consumer electronics. The VCR was a hit because, like television before it, it was neither a replacement nor an improvement, but a brand new concept. Besides increasing their program choices, the VCR brought consumers unprecedented flexibility. They could choose not only what they wanted to watch but also the time they wanted to watch it. Then came the CD-player. It banished for ever all the hisses and crackles that had plagued LPs until then. To the ear, the leap in performance between compact disc and an LP record was even greater than the difference between color and B&W TV was to the eye. Once heard, consumers would

never again settle for less than digital sound. And now, the DAT recorder promises the same leap in performance over cassette decks.

As a result of these innovations, consumers the world over want the sharpest picture, the clearest sound and the snazziest features, all at a price they can afford. Consumers in the wealthier parts of the world are also growing choosier and older. They already have most of the electronic gadgets they want - and are less impressed by the latest fad. So to become a hit consumer product, HDTV must do to color TV in the mid-1990s what the CD-player did to the venerable turntable in the mid-1980s: render it hopelessly obsolete. By making people dissatisfied with the reproduction from their LP records, the compact disc forced music-lovers to replace their turntables with CD players.

HDTV's success depends on many factors, but one of the biggest problems is the size of the box. To truly appreciate HDTV, much larger displays are needed than are available today. In fact, some believe that the HDTV market will not take off until large displays - at least 40-inch diagonal - are available at reasonable cost. But the trouble is that in the larger screen sizes desired for HDTV, direct-view CRTs are bulky, heavy and fragile in addition to being very costly to manufacture. Due to the way they work, CRTs must be almost as deep as they are wide. Few houses have either doors wide enough to accommodate large CRTs or living rooms large enough to conveniently house them. In addition, the weight of a 40-inch CRT display is several hundred pounds, making distribution very expensive.

Currently, the only way to provide HDTV with a picture larger than 36 inches - and anything less makes HDTV look almost as drab as today's television - is to project the image on to a screen hanging on the wall. But market studies have shown that two piece formats - screen and projector - are unpopular with

consumers. For example, while there are now three options available for projection TV, the relative popularity of rear-projection models indicates that the simple bulk of combination units is a barrier to wider consumer acceptance.

**Flat-panel displays key to HDTV's success**

There is no question that manufacturers must package HDTV receivers in a more attractive form. As such, large flat-panel displays will be the key driving factor if HDTV is to realize the multibillion-dollar market projections. Given this urgent need - and a huge market opportunity - companies from around the globe are racing to exploit a number of technologies for flat-panel displays. Exhibit 16 describes the five technologies that hold the most promise for HDTV displays and lists the companies developing them.

About half of the $30 million funds that DARPA announced for a 3-year HDTV R&D program in January 1989 were earmarked for flat-panel displays. Using DARPA funding, Photonics Technology is developing a low-cost 50-inch flat-panel monitor based on plasma technology. Another effort worth noting is by the Japanese NHK, which has already made a 33-inch plasma display panel and is currently working on a 50-inch model. The most ambitious effort, however, is the Giant Electronics Project, a consortium of 12 Japanese firms, initiated by MITI. Between them, they have committed about $400 million ($300 million coming from the industry) to be spent over 7 years to

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32Japan is Ready for HDTV, But the Rest of the World Isn't, Electronic Business, Aug. 20, 1990.


34Photonics predicts that a 60-inch HDTV plasma display might cost only $1,000 in mass production. But that appears a long way off. Photonics currently sells only about 15 of its 60-inch monochrome screens a year - at $100,000 each. Bigger, Wider, Flatter, Brighter: The Key To Making It In HDTV, Business Week, Feb. 26, 1990.

35Japan is Ready for HDTV, But the Rest of the World Isn't, Electronic Business, Aug. 20, 1990.
develop the various technologies needed to produce a 1-by-1 meter high-resolution active-matrix liquid-crystal display (AM/LCD) by 1996.\textsuperscript{36}

There is no question that Japan's electronics giants are pinning their hopes high on flat-panel displays and their unmatched prowess in manufacturing. In AM/LCDs alone, they invested an estimated $690 million in 1989, another $1.1 billion in 1990, and plan to invest at least $1.4 billion more by 1993.\textsuperscript{37} In Europe, big companies such as Philips and Thomson are doing the same.

Still, money alone will not guarantee success, even for the Japanese. Full-color, flat-panel HDTV displays will not be a commercial reality until engineers solve some formidable technical problems. Size and weight, brightness, scaling up, power consumption, viewing angle, response time and manufacturing cost are still some of the critical problems facing flat-panel technologies.

In AM/LCDs, for example, scaling up is a major problem. A typical display in today's TVs has 336,000 pixels. In contrast, HDTV screens will require about 2 million pixels to create sharper, movie-like pictures. While several manufacturers are mass-producing 10-inch AM/LCDs, no one has gotten past the 14-inch barrier, a limit imposed by today's semiconductor fabrication equipment. The millions of transistors the screen requires make fabricating even a 14-inch display a nightmare.\textsuperscript{38} This is because making an AM/LCD panel is like making a very large IC: a 40-inch screen is a 40-inch IC. It is relatively easy to achieve high precision in today's tiny ICs, but doing so across large areas poses formidable technological challenges.\textsuperscript{39} Production yields for even a 5-inch panel are not more than 30% at best. LCDs also suffer from a


\textsuperscript{38}Bigger, Wider, Flatter, Brighter: The Key To Making It In HDTV, Business Week, Feb. 26, 1990.

viewing angle problem. For TV viewers who sit at angles to their screens, the result is a blotchy picture.\textsuperscript{40}

Due to these deficiencies in AM/LCDs, field emission displays (FEDs) - a new approach proposed by Coloray Display (Silicon Valley, California) - has generated considerable interest in the U.S. The approach is based on vacuum microelectronics, a technology that combines the virtues of the vacuum tube with those of the computer chip. The FED's advantages over the AM/LCD are simplicity of structure and thinness.\textsuperscript{41}

One day, large displays only a few inches thick may become cheap enough for use in HDTVs. But that day is unlikely to arrive for many years. At the moment, the technical obstacles appear to be formidable.

\textbf{Competition From Substitute Products}

By the time HDTV is introduced, at least two other television systems, IDTV and EDTV, are also likely to be competing for consumers' dollars. In fact, IDTVs are already on the market. Should any of these less advanced systems catch on with consumers before HDTV takes off, the growth of the HDTV market would be significantly delayed, especially since a modern TV receiver can easily last for about 7 years.

High HDTV receiver costs, large conversion costs by broadcasters and delay in transmission standards could make these alternative products more attractive to consumers. For example, the broadcaster investment to upgrade to EDTV is estimated to be only about $2 million, compared to as much as $15 million for HDTV.\textsuperscript{42} In addition, EDTV receivers would cost only a few hundred dollars

\textsuperscript{40}Flatter, Squarer Eyes, Far Eastern Economic Review, Jan. 11, 1990.

\textsuperscript{41}Flat Out for Profits, Far Eastern Economic Review, April 19, 1990.

\textsuperscript{42}High-Definition Television: The World at War, Economist, Aug. 4, 1990; Poor Man's HDTV?, Business Week, June 24, 1991.
more than NTSC sets; in contrast, an HDTV receiver is expected to cost between $3,500 and $7,000 even in the late 1990s.43 EDTV might also be favored by those small stations and cable operators who need a cheap way to improve broadcasts to avoid losing viewers to HDTV stations.

The market forecasts discussed earlier make conflicting assumptions about the impact of alternative systems on sales of HDTV receivers. EIA assumes that sales of HDTV will be unaffected by sales of the other types. This is clearly unrealistic. HDTV may be more advanced technology than IDTV and EDTV, but without clear signals from consumers, its growth cannot be assumed to occur in isolation. AEA, on the other hand, argues that EDTV would be part of a natural evolution toward HDTV, with consumers shifting to HDTV as prices come down and HDTV broadcasts become more widespread. But it is also just as likely that EDTV will remain a strong competitor to HDTV, rather than an evolutionary stage in the movement to HDTV.

As shown in Exhibit 17, AEA predicts EDTV as becoming a very successful product, with annual sales reaching 1 million units within 5 years of introduction and 13 million units within 15 years; HDTV reaches a similar level within a similar time frame. It is doubtful, however, that two advanced TV technologies will be so successful within the same period. Competing technological starts within the same medium can coexist, but it is just as likely that one will edge out the other as occurred between BETA and VHS formats for VCRs. Coexistence of rival systems requires additional investments by the parties involved and increases their cost of serving the different markets. In BETA and VHS, the video rental stores (and consumers) wanted one standard in order to minimize their investment in any one movie, and their decisions to pick the VHS helped speed the demise of BETA. Depending on the specific nature of the incompatibilities between EDTV and HDTV, the two technologies may or may not be able to coexist.

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43Poor Man’s HDTV?, Business Week, June 24, 1991.
The most important issue, however, is whether consumers will perceive HDTV as a sufficient refinement over alternative systems to justify the additional expense. Judging from the prices forecast by AEA, the price advantages of less advanced systems may be great, especially in the early years when HDTV will cost between $1500 and $2100 more than EDTV and IDTV sets (Exhibit 17).

Development of Industrial Applications
Currently, an HDTV receiver costs as much as a luxury car, and there is no question that most consumers will not buy HDTVs unless prices come down significantly. But as discussed previously, HDTV has myriad promising applications in fields far beyond home entertainment. By using HDTV equipment, Ford Europe, for example, expects to cut the design cycle for new cars from 64 months to 48 months and the number of clay models from over 40 to just 2 or 3.4 The challenge for the consumer-electronics industry, at least in the short term, then is to develop new HDTV applications and find well-heeled commercial and industrial customers who can justify the high cost of first-generation HDTV equipment.

The early proliferation of applications in industrial, commercial and public fields will help acquaint people with HDTV and will promote its popularity for home use. Such applications are also necessary for improvement of HDTV technology and for achievement of scale economies through high production volumes before HDTV becomes a mass product. Industry giants such as Sony and Matsushita realize this, and as such are trying hard to find new niches for HDTV in fields ranging from electronic publishing and teleconferencing to medical training systems and supercomputer graphics.

4Japan's HDTV: What's Wrong With This Picture?, Business Week, April 1, 1991.
Complementary Products and Services

Sales of color TV reached unprecedented levels in the 1980s in part because of the popularity of VCRs, which brought consumers a great deal of flexibility and increased their program choices. Consumers could choose not only what to watch, but also when to watch it. VCR sales, in turn, increased sharply when videotape rental stores became common around the country. Similarly, the demand for home computers has been stimulated by the proliferation of diverse, high-quality software. The development, availability and prices of complementary goods and services could therefore have a significant impact on consumers' willingness to purchase HDTVs. Early development of diverse, low-cost services that appeal to consumers will be especially important if HDTV is positioned as a home information/entertainment appliance.

State of Economic Environment

The history of consumer-electronics products shows that demand for HDTVs will be very sensitive to general economic conditions - levels of disposable income, employment, inflation etc. - and consumer expectations about them. The steady growth in sales of color TV, for example, has been interrupted only by economic recessions. Sales of radio, B&W TV and VCRs have followed the same general pattern. And there is no doubt that a major reason for strong color TV and VCR sales in the 1980s was increased consumer spending due to the booming economy. Growing real income, relatively stable prices, declining cost of consumer credit, and the strength of the dollar in world currency markets all led to strong U.S. sales of consumer durables.

Depending on how many sets are imported into the U.S., exchange rates could have a major impact on HDTV sales. The strength of the dollar was perhaps the single most important factor underlying the surge of color TV and VCR sales in the 1980s. It was mainly due to the increased value of the dollar that TV receiver (all types) component of the CPI declined by 29.8% from 1982 to 1990, while the CPI as a whole increased by 38.6% (Exhibit 10). Thus, TV
receivers were not only getting cheaper relative to other goods and services, their prices actually fell by almost 30% during the 8-year period.

No one can accurately predict future economic conditions. But most experts agree that economic growth in the 1990s will be nothing like the boom of the 1980s. First HDTVs are expected to come on the U.S. market in the mid-1990s. The state of the economy at that time and for several years after introduction would have a powerful impact on how the HDTV market develops.
Chapter 4
Competition and Technical Progress

How quickly HDTV prices drop from their current level and manufacturers make a product that will attract consumers will depend largely on competition and the pace of technological advances in HDTV. But the global race among many high-powered players now underway leaves little doubt that competition in the HDTV marketplace will be fierce and that technical breakthroughs are likely to occur at breakneck speed. This chapter looks at the underlying forces that are driving, and will continue to drive, competition and technological progress in HDTV.

Nature of HDTV Technology
To understand why HDTV has sparked an unprecedented race not only among major electronics firms but also among nations, it is necessary to understand the threats and opportunities inherent in HDTV technology.

A Key, Generic Technology
HDTV is not just a substitute for current TV sets, but its significance goes far beyond TV sets. Several technologies - for high-resolution display, image processing and storage, multimedia services, and the transmission and production of such information - being developed will be used not only in TVs but across the electronics and computing industries. All these technologies are multi-function, multimedia processing technologies. They will driven by HDTV consumer applications in the 1990s, but they themselves are generic driver technologies which will find common application in many fields.

Economies of Scope
HDTV - being a key, generic technology - will result in major economies of scope i.e., production in one area will yield an economic advantage in others, especially due to the use of common technologies. Economies of scope relate in
critical strategic ways to economies of scale. Firms that initially gain a substantial portion of the HDTV consumer market will subsequently be able to reduce their costs through economies of scale and associated learning curve advantages. Such cost reductions will give the initial market winners a competitive advantage not only in the HDTV market, but also in supplier and related electronics markets such as the semiconductor and PC markets.

Vertically- and horizontally-integrated Japanese, and to a lesser extent European, firms are especially well positioned for achieving of economies of scope. They not only can translate a scale advantage from one area into a technology advantage in another, they have in fact done so many times, with devastating results for their competitors. At the country level, a weak position in HDTV will have adverse effects not just in consumer electronics and semiconductors, but also in a host of related industries. The economies of scope in HDTV have several dimensions:

**Interoperable Components**

HDTV technologies will be used not only in TVs but in everything from defense systems to computer displays to CAD systems. Whole parts of HDTVs, such as displays or DSP chips, will be interoperable between various applications. Color LCD technology developed for small TVs, for example, is already being used in laptop computer displays. Similarly, the large-area display technology being developed for HDTV by the Japanese Giant Electronics Project will be useful in all major display technologies - LCD, plasma and thin-film transistors - and will also have many other applications in fields ranging from copiers to touch panel screens to solar batteries. Interface technologies, such as displays, are key to the success of many firms in the computer industry. Modern defense systems and CAD systems also depend critically on display and display processing technology. Firms that achieve significant scale economies and dominate HDTV display technology could make considerable inroads in computer, defense and CAD systems industries.
Technology Merging
HDTV technologies will also create economies of scope through their use in integrated systems which merge the functions of several different existing products. The "TV set" in a home will pack enough processing power and memory to serve as a stand-alone computer or as a node on a whole host of networks. The merging of product technologies will lead to a merging of the product themselves. It will be technologically simple to add an HDTV display to these systems and make them TV/computers. When this happens, PC and workstation makers will be in for a new and very dangerous threat in a substantial portion of their market.

Technology Platform
HDTV could also become the platform for a wide range of peripheral devices, such as printers, copiers, cameras and VTRs. Canon, for example, has developed a new version of its full-color copier and a series of interface modules through which the copier can accept input images from TVs, computers, VTRs, cameras, and electronic still cameras. The machine can function as a simple copier, and images from all sources can be assembled, edited and processed with an attached PC before printing.

Underlying Technologies
HDTV will create economies of scope through the common application and development of the underlying technologies, as opposed to the components, that will be used in HDTVs. Electronic packaging, new algorithms for digital signal (image) processing, and parallel processing are examples of these underlying technologies. The fact that Japanese are learning to mass apply these technologies in low cost ways in their HDTV development efforts holds serious implications for many electronics firms elsewhere. These three technologies are among the most important underlying technologies in supercomputers, computer graphics and computer-aided design - areas in which the U.S. firms currently hold a lead.
Forward Linkages

Finally, firms which control the flywheel applications of HDTV will in all likelihood be the ones to capitalize on whatever forward-linked (or successor) technology applications arise from HDTV. Some of these applications can be seen now; others will become visible only with time and experience. Applications of HDTV in other systems such as traffic control systems, plant monitoring, long-distance diagnosis and automotive on-board navigation systems will be endless.

Beyond the forward linkage to large systems, HDTV is very likely to push the state-of-the-art in computer interface technologies. Visualization - an important technology for scientific problem solving, design and other areas - depends critically on advances in display and display processing capabilities. Beyond visualization, artificial reality is emerging an important technology. Advanced digital processing and display technologies are already applied to simulation systems, such as pilot training systems, and HDTV will carry them several steps further. Simulation systems, in turn, will evolve into a total environment (an "artificial reality") in which the participant will be unable to distinguish between the artificial and the real. By losing the underlying technologies to others, the U.S. could very well squander its present lead in simulation and other advanced applications of man-machine interface technology.

In summary, HDTV is a leading-edge and critical technology with enormous capability to affect most sectors of the electronics industry. The spill-over effects of HDTV technology are likely to impact many other industries such as optics, glass, graphics, automated manufacturing equipment, computers, semiconductors and telecommunications. Any firm whose products depend upon this or related technologies to even a small degree could find control over its own profits at risk. As a result, the economic significance of HDTV technology is much greater than sales forecasts alone would suggest.
It is also important to note that many of the HDTV technologies are process intensive. Examples include the manufacture of displays and of special purpose DSP chips. Because process secrets are often extremely difficult and expensive to learn and fairly easy to conceal from competitors, a dominant technological power can create enormous entry barriers for competitors whose technology lags behind. Japanese and Europeans fully appreciate the economies of scope made possible by HDTV and are working hard to capitalize on them.

**Incentives for Consumer-Electronics Industry**

HDTV has become the consumer-electronics industry's primary horse race. Major Japanese and European firms are investing billions of dollars in HDTV. In 1990, 29 Japanese firms spent $1.1 billion between them just on LCD developments. Sharp alone is investing $770 million over 3 years to improve its LCD output. Europeans appear to be outspending even the Japanese. Philips and Thomson are putting $4 billion in a joint project to develop HDTV technology, with Thomson alone investing $122 million a year over the next 5 years.¹ And most HDTV manufacturers, including Matsushita, Sony and Thomson, are setting up major production facilities to make their own chips.

There are several reasons why major consumer-electronics firms are betting their future on HDTV. The large potential market for HDTV and the likely gains due to economies of scope are certainly the key reasons. But there is more behind the industry's keen interest in HDTV. The industry desperately needs another blockbuster product in order to revitalize itself.

Exhibits 18 and 19 summarize the story of the consumer-electronics industry over the last several decades. The years when the industry's output surged annually by 50% or more have long gone. For the leading firms, good years are now measured more in terms of 10-15% growth. In 1990, output of the

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Japanese consumer-electronics industry as a whole rose by just 3.8 percent. The estimate for 1991 is a mere 3 percent. For consumer-electronics firms, that kind of growth barely covers their rising R&D costs, let alone the capital investments needed to keep one step ahead of the competition. As a result, many smaller firms have already fallen by the wayside and the bigger ones find their future at stake.

The major reason behind the crunch in consumer electronics is that current breadwinners for the industry have reached maturity (Exhibit 18). From the late 1970s until 3 or 4 years ago, the VCR was the locomotive for the whole industry - from the big producers such as Philips, Sony, RCA, Matsushita and GE down to the smallest of parts suppliers. At its peak, the VCR accounted for almost half the output of the entire consumer-electronics industry - as did TV at its own peak. The trouble is that almost everyone who is likely to own a VCR or color TV now has one. In Japan 99% of all households now have a color TV, 80% a VCR, 61% a stereo system and 42% a CD player. The U.S. and European markets are not that far behind.

To fuel their future growth, companies know they have to come up with a new product that can capture the consumers' fancy once again. While they are pushing a bewildering number of new products at consumers, nothing else offers the potential jackpot - or threat - of HDTV. On one hand, consumer-electronics firms see HDTV not only as a promising multi-billion dollar market, but also as a platform on which to build all sorts of digital gadgets for consumers. On the other hand, the trend toward digital electronics threatens the future of many companies. If anything, HDTV - which is nothing less than a high-speed computer in disguise - promises to accelerate that trend.

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The trouble is that technologies that are crucial for HDTV and other future consumer-electronics products are strongholds of the computer industry. Most big consumer-electronics firms have been making PCs, but the amount of information that has to manipulated, stored and projected continuously on to an HDTV screen requires much more computing power. Some even say that companies wishing to stay in the race must have the know-how for making computers and telecommunications equipment as well as consumer products. The industry giants are thus setting up major facilities to produce their own semiconductor chips and grabbing all the computer know-how they can find so as not to become dependent on the computer industry for vital components. But computer makers are not looking the other way as consumer-electronics firms prepare to invade their turf.

**Incentives for Commercial Electronics Firms**

For their part, computer firms see HDTV not only as a threat to their business, but also as a perfect entry point to grab a chunk of the promising home-leisure business. As discussed earlier, the significance of HDTV goes much beyond TV sets. Many view HDTV as a driver technology that will have a major impact on commercial electronics for four primary reasons:

- HDTV receivers rival advanced PCs and workstations in both the number and the technical sophistication of chips they need.
- Manufacturing techniques and equipment for printed circuit boards and system final assembly will be shared by HDTVs and computers.
- Tight engineering/manufacturing links that speed product development are largely pioneered in consumer-electronics, but are becoming vital in commercial electronics as product life cycles shrink.
- HDTV will use huge quantities of semiconductors, especially DSPs and DRAMs. According to MIT’s Prof. Schreiber, HDTV will become the world’s biggest consumer of chips.⁴

Computer manufacturers therefore have several reasons to get in on HDTV. For one, HDTV receivers may finally transform the computer from a machine used largely in business into a mass-market consumer product. HDTVs will have enough information processing power to function as computers when not in use as TVs. They would need only the addition of a keyboard and a disk drive. The big, clear displays would increase the attractiveness of home information services. But even more important, computer firms may have to get into HDTV manufacturing just to remain abreast of technology and to keep their own costs competitive.

In fact, many U.S. electronics firms fear that, once HDTV is established, Japanese manufacturers may be in a position to wipe out the U.S. computer and semiconductor industries. And they are scared that the Europeans might be right behind the Japanese. The AEA claims that if the U.S. sells fewer than 10% of the world's HDTVs it will lose half of its share of the PC and chip markets. Even to maintain its current market shares, it needs to control over half the HDTV market. AEA argues that the technology developed to serve the HDTV receiver market will allow foreign firms to become dominant in other electronics markets, from PCs to telecom equipment to workstations. The loss of the electronic goods markets will subsequently entail a loss of the markets for the components used in those goods, especially semiconductors.

In short, HDTV is a fundamentally different product from others in consumer electronics. It has the technical content of a computer or workstation, but will ultimately have the high volume associated with consumer electronics. Whereas advanced technology used to "trickle down" from advanced military systems, the latest developments are beginning to "trickle up" from the consumer side. And since new fabrication methods will have to be devised to meet tough technical requirements for HDTV, the firms that develop and perfect HDTV technologies into efficient manufacturing processes capable of

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high yields at low cost will have gained a huge process edge over competitors that could be used to capture other markets.⁶

Regardless of who eventually wins or loses, the implications for HDTV are clear. Competition in HDTV will be brutal, and technological advances will come in rapid order as firms hustle to gain an edge over their competitors. The strong presence of both of these elements means lower prices for consumers and faster market penetration for HDTV. Exhibits 20 and 21 show some of the HDTV technology development efforts by Japanese and European firms.

Color TV has become the biggest hit ever in consumer electronics. Yet it took 9 years to reach 1% household penetration. The single most important factor behind color TV’s dismal market performance during the early years was a lack of color programming. There were two major reasons why color programming increased only slowly. First, TV programs were much more expensive to produce in color than in black and white. Second, there was no competition. The three networks - NBC, ABC and CBS - controlled both production and distribution of TV programs.1 Because networks faced no threat of losing their audience share even if they did not broadcast in color, both ABC and CBS decided to do just that.

Color TV survived only because RCA, which had invested millions of dollars in developing color, kept pushing it, and NBC, then owned by RCA, continued adding color programming - at a loss. Some have argued that future prospects of HDTV are doomed because no such alliance exists today.2 The fact is that there are at least two such alliances. Having taken over major U.S. film studios and their libraries, Sony and Matsushita - two of the biggest movers of HDTV - could crank out HDTV movies, VCR tapes and cable-TV shows to whet consumer appetites for wide-screen, high-resolution TVs.

Even if no alliances existed between HDTV hardware manufacturers and software producers, there are very powerful market and economic forces at work in the HDTV market that should ensure rapid availability of programming and push HDTV receivers into America’s living rooms in a relatively short time.

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1Cable TV existed, but only as an appendage to broadcasters. Even in 1962, eight years after the introduction of color TV, a mere 1.7% of TV homes had access to cable.

**Program Production**

While the controversy over production standards still continues, HDTV is already well on its way to becoming the medium of choice for producing programs. Movie makers, TV networks and independent producers are discovering that HDTV production equipment is an efficient, effective and economical alternative to the 35mm medium now widely used in producing movies and TV programs. In the past, 35mm film had an overwhelming advantage due to its vastly superior image quality. But HDTV removes that edge. In addition, the cost of 35mm film production has been rising about 15% per year and is becoming a real constraint, according to CBS.³

Production using HDTV equipment is rapidly gaining favor among moviemakers and TV program producers for a variety of reasons. First, HDTV production offers all the convenience and flexibility of video yet matches or exceeds the picture quality of 35mm film. In addition, it offers enormous advantages in terms of monitoring during (or just after) shooting. Second, it reduces the production time needed and allows special effects to be introduced much more easily than is possible with conventional film-making methods.⁴ According to Barry Rebo of Rebo High Definition Studio, HDTV allows producers to do things that are not possible in either film or conventional television.⁵ Third, HDTV cuts post-production costs by eliminating film processing and the inherent delays associated with it. Finally, a wide range of production equipment, including cameras and tape conversion and editing equipment, is already widely available.

Using this equipment may lead to significant economies in the production of movies and TV programs. It is estimated that producing a one hour television

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⁵Television Makers are Dreaming of a Wide Crispness, Business Week, Dec. 21, 1987.
drama in HDTV can reduce production costs by 15% compared to 35mm film.\textsuperscript{6} CBS estimates that an HDTV video can be produced for about half the cost of film.\textsuperscript{7} More recent estimates from producers, however, indicate that HDTV equipment often leads to production savings of around 30 percent.\textsuperscript{8} Lower cost HDTV production would be useful even without consumer HDTV because HDTV-produced programs can be easily converted to 35mm film for theatrical exhibition as well as to existing conventional videotape for TV transmission.\textsuperscript{9} Thus, there has been considerable impetus to move to HDTV production even before HDTV distribution to viewers is possible.

HDTV also promises to lower distribution costs, which are currently substantial. HDTV digital transmission will allow links between television studios, in which the signal must be carried high objective quality. Films produced using HDTV could be transferred to 35mm film and distributed as they presently are. However, since no present electronic distribution system exists for film, the film industry could obtain satellite space with wide bandwidth and transmit movies through satellites and earth stations to theaters. Or tapes - rather than heavy, bulky film reels - could be distributed through the conventional film distribution chain and exhibited like large screen TV, only with much higher quality.

The only major impediment to widespread use of HDTV production equipment is its high initial cost. HDTV studio cameras and editing systems typically cost twice as much as conventional NTSC-based hardware, according to market


\textsuperscript{7}The Push for A Sharper Picture, High Technology Business, April 1988.

\textsuperscript{8}Japan is Ready for HDTV, But the Rest of the World Isn’t, Electronic Business, Aug. 20, 1990.

\textsuperscript{9}J. Rossi and R. McMann, The 1125 HDTV Production System and Its Relationship to NTSC and HDTV Broadcast Systems, Jan. 13, 1988. In fact, conversion of HDTV programs produced with an 1125/60 production system for broadcast on NTSC television results in a higher quality product than if the program had been produced instead with 35mm film and converted to NTSC. In addition, the cost of HDTV conversion is low.
leader Sony.\textsuperscript{10} However, more than 35 manufacturers from the US, UK, France, Belgium, Switzerland and Japan are marketing production equipment for the Japanese system and costs are coming down rapidly.\textsuperscript{11} In 1988, for example, HDTV equipment cost 3 times the price of conventional video equipment.\textsuperscript{12} Despite the stiff initial cost, however, numerous studios are now using high-definition video to produce everything from 30-second commercials to feature-length presentations to $100 million films such as Columbia Pictures' "Hook" released recently.

There are other factors that are likely to ensure rapid availability of HDTV programming. Under a 1970 consent decree with the FCC the networks gave up control of much programming and allowed independent program producers a market in which to sell their productions. In fact most programs are supplied to the networks and the other TV systems by just 8 major movie studios: Columbia, Disney, MGM/UA, Orion, Paramount, Twentieth Century-Fox, Universal and Warner.\textsuperscript{13} But for the film industry, TV and VCRs have become the major market, replacing the box office. As early as 1986, box office revenues in the U.S. for films were $1.6 billion while video sales and rentals for home use exceeded $2 billion.\textsuperscript{14} Now over 70\% of U.S. households own a VCR and rent over 4 movies each month on average. So, given the economics of HDTV production, there is a great incentive for movie studios to release movies produced in HDTV. Even if there were no VCRs, studios would still want to switch to HDTV production to gain a cost advantage over their competitors.

\textsuperscript{10}Japan is Ready for HDTV, But the Rest of the World Isn't, Electronic Business, Aug. 20, 1990.


\textsuperscript{12}The Push for A Sharper Picture, High Technology Business, April 1988.


Networks and other delivery media could thus get programs produced using HDTV equipment even if they are not ready to deliver HDTV to consumers.

Another factor that favors production of HDTV programs is the FCC requirement that HDTV must be backward compatible with NTSC. Every potential HDTV program producer is thus guaranteed a large TV audience regardless of the market penetration of HDTV receivers. At the same time, the backward compatibility of HDTV may slow its market growth. Consumers may not want to spend $3,000 or so on an HDTV set purely for an improved picture when they might watch the same programs on their old televisions.

Program Distribution
Production of HDTV programs will do little good for HDTV's rate of market penetration if the various delivery media refuse to transmit them to consumers. But that is unlikely to happen. The potential threats and opportunities created by HDTV have already started a power struggle among the distribution media, and HDTV transmissions are likely to begin soon after its introduction.

Broadcasters and cable TV operators distribute most of the TV programs to consumers today. Satellites mainly fill the needs of those not served by cable TV or who are too far from TV stations to receive a good signal. HDTV could change the competitive balance between these various media and is likely to spur the delivery of TV programs by other means, including direct broadcast satellite (DBS) and optical fibers through the telephone system.

HDTV has sparked major concerns among the various media. Broadcasters fear that if HDTV came first to cable or DBS, it might make their programs quite literally look bad. They might then lose revenue as advertisers switched to other media. Those who run cable systems or might operate DBS systems have the opposite fear: that standards set for broadcast HDTV would be less than ideal for their systems. Cable operators are already fearful that high-resolution
Super-VHS videotaped movies and other entertainment programming will win customers away from inferior pictures on pay-for-view movies on cable. All three groups wonder whether fiber-optic cable, with its inherent wide bandwidth, might manage to gain an early HDTV foothold in U.S. homes. And if HDTV should reach consumers first in the guise of HDTV VCRs - which could happen if standards setting takes too long - will consumers then reject broadcast TV out of hand as inferior?

Many of the competing media look to HDTV as an opportunity for them to capture market share from terrestrial broadcasters by use of their greater technical potential and flexibility to transmit high-quality HDTV to consumers. Broadcasters have little to gain and a lot to lose in such a contest.

Cable TV and videotape will probably force the issue for broadcasters. HDTV videotapes are likely to be available soon after HDTV's introduction. Similarly, HBO and other cable programmers may transmit selected shows in HDTV. The cable industry is ready to embrace any technology that gives it an edge over its broadcast competition. HDTV could represent a way to wipe out cable TV's second-class image. In fact, if HDTV catches on in cable and videotape before the networks are ready to follow suit, there is a very real threat that broadcasters will become secondary to other sources of programming.

**Terrestrial Broadcasting**

While TV set manufacturers confronting slumping sales view HDTV as a potential jolt of adrenaline, for broadcasters it is pure poison - all extra cost, no extra income. Far from embracing HDTV, broadcasters are being "dragged kicking and screaming into it."\(^{15}\) And with good reason. According to the latest estimates, based on separate studies by CBS and PBS, adding the necessary equipment to broadcast HDTV would cost from around $1-2 million for a station that simply wants to pass along a network feed to $10-15 million

for a major station with an HDTV production studio.\textsuperscript{16} Yet that capital investment probably would not noticeably increase the size of the viewing audience, because most if not all HDTV viewers would be converts from NTSC, and they are already watching the broadcasters' programs.

Nevertheless, terrestrial broadcasters are bound to move into HDTV sooner or later. The motive is defensive - they cannot afford to be providing a picture inferior to what is provided by cable and satellites. According to Andrew Lippman of the MIT Media Lab, "It is true that if no such thing as high-definition TV had ever been invented, broadcasters would be quite happy with the way things are. After all, you compete as a broadcaster on program content. The problem with high definition is that you may in the future be able to compete both on the basis of content and quality, if an alternative media broadcaster adopts a standard of higher quality."\textsuperscript{17}

Satellite and cable broadcasters have been steadily eroding the networks' market share. In 1977, 93 percent of households watched one of the three major networks - ABC, CBS or NBC. In 1988 the figure was 70% and less than 44% of all households in prime time.\textsuperscript{18} None of the three networks would want to see the advent of HDTV accelerate that process.

And cable and satellites do not suffer from the same constraints - either in terms of conversion costs or broadcast spectrum. To convert to HDTV, terrestrial broadcasters would have to buy new production equipment, new transmission equipment and possibly even new transmission towers. Cable operators, however, only have to consider new production equipment and relatively inexpensive equipment to adjust the transmissions currently sent

\textsuperscript{16}The U.S. Wins One in High-Tech TV, Fortune, April 8, 1991.

\textsuperscript{17}A High-Tech, High-Stakes HDTV Gamble, Editorial Research Reports, Feb. 17, 1989.

over their wires. Satellite broadcasters are still in the start-up stage and have not invested a great deal in production equipment, so for them to adopt HDTV would involve no extra expense.

Cable Television
Cable TV has become the broadcasters' worst nightmare. It is growing rapidly, both in subscribers (Exhibit 22) and in advertising revenues - at the expense of broadcasters. Cable advertising revenues were projected to grow 19% to $3 billion in 1991, up from just $200 million 10 years ago. Cable penetration in the U.S. reached an all-time high of 59.2% in February 1991, an increase of 6% from February 1990. Average 24-hour audience share for cable shot up from 19 in the 1985-1986 season to 34.5 for October 1990 through January 1991. As early as 1988, TeleCommunications Inc. (TCI) - the largest cable operator - had a cash flow greater than the three networks combined. Although the name is less familiar to most TV viewers than the names of the networks, by the late 1980s TCI was more powerful and influential than any of the networks.

Despite its phenomenal success, cable still suffers from a second-class image. Consequently, cable looks upon HDTV as a perfect opportunity to wipe out that image and to make further inroads into broadcasters' audience share. Since their signals travel through wires, not over the air, cable operators do not face the same spectrum problems as broadcasters. Nor are they regulated by the FCC - though the momentum to have the FCC do so is quickly building up. Moreover, market studies show that affluent cable viewers would be the prime

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\(^{19}\)The FCC ATV Advisory Committee has estimated that the cost of introducing 12 channels of HDTV programming on a cable TV system serving 100,000 subscribers would be only about $1.9 million.


\(^{21}\)Basically, Cable Hits a Hot Spot, Advertising Age, April 8, 1991; Cable TV Critiqued, Advertising Age, April 22, 1991.

targets for HDTV. At the same time, cable is extremely concerned about losing viewers to VCRs and shivers at the thought of having to compete with the telephone companies. It is therefore likely to be one of the first media to offer HDTV programming.

Cable TV has another ace in the hole, more channels than any of the competition. This gives it the capacity to experiment with new ideas until it stumbles, blindly or intelligently, upon the right combination. The average cable customer lives in an urban or suburban area and can receive as many as 50 channels of television programming. With fiber-optic technology, up to 100 channels could be offered, with bandwidth available for the integrated services digital network (ISDN), picture telephone, interactivity, and other functions.

**Direct Broadcast Satellites**

There is currently no DBS service in the U.S. The DBS industry, however, is banking heavily on HDTV to make DBS a viable delivery medium. Hughes Communications, NBC, Cablevision, and Rupert Murdoch's News Corp. have agreed to launch Sky Cable, a $1-billion DBS service to start in 1993. Some believe that DBS could "cherry-pick" the most lucrative HDTV opportunities and poses a formidable threat to cable-based or other delivery systems. Success of DBS, however, will greatly depend on the size and cost of receiving dishes, and its ability to deliver a wide variety of programming.

Others believe that DBS is likely to stimulate the cable industry more then it would create a demand for home dishes. The proliferation of new programming services from DBS would stimulate the demand for cable service

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24Telco/Cable Crossownership Is Important; So Is Access to Programming, Rural Telecommunications, Winter 1990.
because cable is the only distribution method that can bring all these services into the home. People will want the convenience of cable and will appreciate the fact that cable will be able to give them a lot more choice in programming. Furthermore, a large segment of the mass market is not likely to part with considerable sums of money needed to receive the DBS programming.28

Telephone Companies
The balance of power among delivery media could shift considerably with the entry of yet another player. Phone companies are eager to provide TV service over their digital fiber-optic networks. Right now, they are barred from doing so. But if legal restrictions are lifted, phone lines will be able to carry higher-definition images than any other medium.

Optical fibers capable of carrying thousands of digitized phone calls now serve intercity trunk lines. Extended directly to the home, optical cables could deliver telephone conversations, computer data - and HDTV. Some experts believe that fiber optics will become the primary conduit for video to the home - but not until well into the 21st century.29 The phone companies are gearing up, despite a current ban on their entering the business. Bellcore, the R&D arm of the eight Baby Bells, has conducted field trials sending video signals over a fiber-optic network linking eight cities. Bell of Pennsylvania has put fiber optics in 100 homes in Perryopolis. And GTE has conducted a 5,000 home test in Cerritos, California.30

The threat from the phone companies is alarming the cable operators. But there is growing support for letting the Baby Bells go ahead. National Telecommunications and Information Administration (NTIA), for example, has


29Super Television, Business Week, Jan. 30, 1989. Huge investments are required to replace the existing copper wires to the home with fiber optic cables. Copper wires do not have sufficient capacity to carry HDTV signals.

suggested that phone companies be allowed to offer video transmission as a service - but not own the content.\textsuperscript{31}

**Recorded Media**

Finally there is another simple means by which HDTV programs can be delivered. VCRs are having a devastating effect on pay television and dramatically altering the film industry. The VCR both complements and substitutes for video received by broadcasting, satellite, or cable.

The availability of VCRs will be critical since, initially at least, there will likely be little programming available from other distribution media. Even after a transmission standard is selected by the FCC, there may be a substantial lag before an appreciable amount of programming will be available in HDTV.

The VCR will very likely be the first medium available for distributing HDTV programming and, for a while, it may well be the only one of consequence for most consumers. And it is probably the threat from VCRs that will force the other media to begin offering HDTV programming quickly.

\textsuperscript{31}Super Television, Business Week, Jan. 30, 1989.
Chapter 6
The Future of HDTV

Earlier chapters discussed a variety of obstacles to quick and widespread market penetration of HDTV. But there is no good reason for assuming that the full, potentially adverse effects of these obstacles will in fact come into play. Similarly, there is no basis for ignoring completely such an outcome.

The fact is that a combination of continuing delay or uncertainty about standards, high and sticky receiver prices, delay in availability of programming, a dismal economy, and a decline in disposable incomes, for example, could seriously hurt HDTV's market growth. And, since there has been no meaningful market research on consumer acceptance of HDTV, it may be that consumer preferences for better TV pictures - though quite positive - are simply not strong enough to warrant the additional expense of an HDTV set. For many consumers there may be diminishing returns to video gadgetry to receive basically what are still the same programs.

On the other hand, a timely and firm resolution of standards, rapid availability of high-quality programming, high levels of consumer spending, sharply declining prices and fast improvements in product quality, for example, could help HDTV become a hit consumer product very quickly.

It is important to note that receiver costs and program availability will be determined to a great degree by the size of the market. HDTV - like its predecessors - therefore faces a series of "chicken-and-egg" problems:

- Consumers are unlikely to buy receivers until a wide variety of HDTV programming is available; but broadcasters hesitate to offer HDTV programs until there are enough viewers to make it worthwhile.

- Consumers are unlikely to buy receivers until the cost comes down to acceptable levels; but manufacturers can't get the cost of receivers down until millions of consumers are purchasing HDTVs and enable large-scale mass production and streamlined manufacturing processes.
These two factors were the key reasons behind the disappointing growth of color TV during its first 9 years. Only the perseverance of RCA and the investment of about $3 billion (1988 dollars) kept color TV alive until the necessary critical mass of color programming became available and enabled the market to grow. As discussed previously, however, there are strong market forces at work that should help HDTV break out of these circles fairly quickly.

Yet no one can foresee how the HDTV market will develop. HDTV might prove irresistible to consumers and the market may grow rapidly, with corresponding economies of scale quickly lowering costs and making HDTV appealing to even relatively conservative buyers. The HDTV market might grow more slowly; growing only after much larger and improved displays are available; after consumers are sensitized to the value of its higher picture quality; and after a variety of quality programming is available. Less advanced versions of television such as IDTV or EDTV might prove more than adequate for most consumers, limiting HDTV to a small high-end residential market and to movie theaters, hotels, bars, resorts or restaurants, where it may play a prestige enhancing role. Or perhaps lower resolution interactive video systems will reach a level of performance sufficient to stimulate consumer interest and vie with HDTV for consumer dollars.

HDTV may suffer the fate of other heralded innovations, like the picturephone, quadraphonic stereo, AM stereo and not escape the innovation stage. It may languish like teleconferencing, two-way cable TV, videotext or DBS. Or, the development of the market may be long delayed as a result of the FCC's indecision or inaction, as in the case of cellular telephone. While any of these scenarios is quite possible, the special circumstances that led to such dismal market performance are clearly not inherent in these technologies and are in many essential respects avoidable.

The recent rapid growth of the premium television receiver market and the phenomenal success of previous home entertainment products like color TV and
VCR indicate that consumers will pay premium prices for real improvements. Both color TV and VCR required substantial consumer expense as measured by product price as a percentage of household income. The is no doubt that consumers are price sensitive, but HDTVs, in current dollars, will cost no more than monochrome sets in 1947 or color sets in 1954. As manufacturers move down the learning curve, HDTV prices are likely to fall to a modest increment over current TVs of the same screen size. The initial market penetration is likely to be slow, but the chances of eventual acceptance by the consumers are quite high, barring some unforeseen problem.\(^1\)

The introduction of HDTV is likely to redefine the standard of quality in video entertainment for the foreseeable future. Over the years there have been numerous examples of strong consumer preference for high-quality audio and video products, and HDTV should be no exception. Consumers will quickly become accustomed to having large, wide-screen pictures with the quality of 35mm film and digital stereo sound in their own homes. Just as color TV replaced B&W, FM radio eclipsed AM, and compact discs have overtaken LPs, HDTV will make the current TVs obsolete and set a new benchmark.

A factor that strongly favors the eventual development of a huge market for HDTV receivers is the likelihood that they will be used for many applications other than viewing regular TV programs. What attracts the telcos, computer firms, and others is the prospect of developing a host of new informational, transactional, educational, and entertainment services, as well as the use of the HDTV display with VCRs, computers, and electronic still cameras.

\(^1\)A major obstacle would be a depression, or the use of mutually incompatible standards and receivers by the various media. While government policies can deal somewhat moderately with the first problem, they can positively prevent the second from ever arising.
HDTV As A Home Information Appliance

Like everything else about HDTV, the role of HDTV as a consumer product in the future information society remains controversial. Skeptics portray HDTV as simply providing better entertainment for "couch potatoes" and claim that there will not be a sufficient consumer market to support a more advanced technology. Advocates portray HDTV as the basic technology platform on which tomorrow's home and perhaps even office information services will be built.

Three things will be essential if HDTV is to become a home information center: development of a national two-way broadband fiber network; availability of diverse information services at low cost; and consumer demand for those services. Neither fiber-to-the-home nor a wide range of information services is likely to be a reality until well into the 21st century. Therefore, while HDTV might eventually evolve into an information appliance for the home, it is unlikely to do so in the near future.

The infrastructure needed to create a vigorous, nationwide information services market can be best developed with the participation of telephone companies. As judge Greene has noted, "Because of their presence everywhere and their relationship with every user of the telephone, only these companies will be able to furnish the necessary infrastructure components for the distribution of efficient services on an integrated basis ..." Large investments will be needed if the telephone network is to provide the capacity and switching necessary for carrying HDTV signals. If this is to happen, optical fiber technology and optoelectronic switching devices will hold the key. The telephone companies want to install fiber-optic cables for residential as well as business customers, but rewiring U.S. homes could cost $200 billion.

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2Telephone companies are currently barred from distributing video signals.
3The copper wires now providing telephone service to U.S. homes do not have the capacity to carry real-time, high-resolution, full-motion video.
With the declining costs of optical fiber, the extension of fiber to the home is expected to become more affordable. Some estimate fiber may be cost-effective for large, new housing developments by 1992. There are optimistic projections that 17 million homes and small businesses could be hooked up to fiber by 1999. The very high information carrying capacity of fiber may make it the carrier of choice for HDTV in the future; and if HDTV market develops, it could further stimulate the use of fiber - initially in the cable backbone and later to the home. Some industry experts argue that if HDTV does in fact take off, fiber to the home is almost a sure thing.

In the near- and mid-term, however, coaxial cable will continue to be the most important medium for carrying video signals to the home. The Integrated Services Digital Network (ISDN) will allow a host of information services short of high-quality, real-time video. Whether or not a mixed cable TV and telephone company network can evolve into a national two-way broadband fiber network is unclear.

Little reliable information is available on consumer demand for interactive video. Computers, rather than HDTVs, could be the platform for interactive services in the future. Interactivity is largely a function of flexible computing power and good software - in sharp contrast to the very high speed but relatively inflexible signal processing done by an HDTV. Declining costs have already brought computers into about 28% of U.S. homes. A recent survey,

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6The most advanced system today can transmit information at the rate of 3.4 billion bits per second on a single pair of fibers. Telecommunications in the 1990s, Business Horizons, Jan-Feb. 1990.
8Telecommunications in the 1990s, Business Horizons, Jan-Feb. 1990.
however, found that home computers are used, on average, just twice per week; and many question whether they will penetrate the remaining 72% of households any time soon. On the other hand, the potentially large household penetration of HDTV would allow the delivery of interactive information services to more consumers.

Poor results with videotext and in the home-computer market may seem to indicate that consumers do not yet see a great need for home information services. Nevertheless, if HDTV and fiber-to-the-home do materialize, a general purpose HDTV terminal/entertainment/information center could be the next step. This would be a two-way communications system that could spur dramatic, synergistic growth in pictorial communications, multimedia database services, home shopping, educational services, and the trend toward working at home. Consumers will have instant access to a huge range of network resources. They will be able to send and receive information anytime, anywhere and in any form - voice, data, image, or video.

In the long term, having an advanced HDTV with the capability of interactivity might be very attractive to consumers. These systems might allow consumers to create personalized newspapers; browse distant databases; request more in-depth information on news programs; transmit an interesting movie clip to a friend; or even use an electronic yellow pages to see a video clip of the inside of a restaurant they want to try. Alternatively, such services might be provided by a telecom/computer system while the HDTV simply provides entertainment. Or consumers may decide that such interactivity is not worth the cost or effort in either case.

Although such scenarios suggest that HDTV might eventually become the home information center - providing entertainment, computer and telecommunications services - it is perhaps more likely that these services will instead continue to be primarily provided by separate, specialized pieces of equipment. People simply work that way. While the teenager is keeping the
videophone busy, one parent could watch television on a big screen in the family room, while the other parent could use the computer in the study room to balance the monthly finances.

HDTV might thus be one of three platforms for home information services; the others being the computer and the videophone.\textsuperscript{11} All three types of equipment will probably evolve toward common basic designs that allow easy exchange of information among them and could significantly overlap in services they provide. Over time, it may become increasingly difficult and moot to distinguish these different types of digital equipment from each other. The large, high-quality screen of the HDTV might be the most notable difference.

These video information services will neither replace today’s media quickly nor will they become widespread until they provide much greater functionality at an affordable price. For example, simply reprinting a newspaper story on a bulky, hard-to-read HDTV or computer display will not induce people to give up the convenience of newspapers, which can be carried around and read anywhere. But video information services that deliver more in-depth information on a news program on request; can send a movie clip to a friend; or provide electronic yellow pages that include video clips of restaurants that viewers might want to try could attract a great many newspaper readers.\textsuperscript{12}

\textsuperscript{11}In homes that do not otherwise purchase a computer, the HDTV might serve as an affordable means of providing some computing power and would then open a wide range of services.

\textsuperscript{12}Should the U.S. Free the Baby Bells, Business Week, March 12, 1990.
Box I

Applications of HDTV Technology

HDTV represents a revolutionary improvement in visual communication. As its applications described below indicate, HDTV is likely to encompass an enormous range of markets - far beyond television.

Telecommunications: HDTV will bring "face-to-face" video communication anywhere in the world and let people share drawings, photos, recordings, film clips, documents and spreadsheets on the screen as they converse. It would permit home banking, home shopping and use of data sources. A host of new services, ranging from videophones and teleconferencing to telemarketing new goods could become available. With video networking, a prospective tourist could take a "stroll" through mountain resorts that he is considering visiting. Similarly, a news service could "publish" an electronic version of a daily newspaper that is edited to a reader's particular interests.

Education: HDTV could be used widely in education, from pre-school through medical school. Advances in manipulating digital video allow the viewer to interact directly with real-world images. For example, the viewer can "walk" through an ancient site at will, the computer selecting and displaying the appropriate audio and video signals in response to the viewer's direction. The viewer could similarly examine the effect of different strategies on the outcome of a battle; take apart and rebuild an auto engine; or dissect a frog, with detailed information available on demand on how each part works individually and with others. This ability to interact with what is being displayed will make these technologies far more important to education than today's TVs.

Medicine: Advanced video communications technologies could be used to transmit medical images such as x-rays, CAT scans, or color pictures of tissue to leading experts in distant cities for instant diagnosis. Because of HDTV's high resolution and truer rendition of color, these images would be so highly developed that microscopic procedures involving tiny veins and arteries could be clearly viewed by the distant specialist offering assistance. A distant expert might even observe and provide advice during a critical operation. In addition, HDTV might allow sharing of expensive medical equipment, such as the CAT scan, among several hospitals, thereby lowering the cost of medical care for consumers. Such applications of HDTV technology could especially benefit people in rural areas with little access to world-class medical facilities.

Simulation: A major application of HDTV appears to be as a scientific and engineering tool. HDTV's ability to display high-resolution live images that can be manipulated by computer could revolutionize engineering simulation, including computer aided design of structures, electronic components and equipment, aircraft and many others. Designers of automobiles and other products are already using HDTV together with CAD tools to speed up product development. HDTV lets (Continued...)
designers take a realistic, computer-generated rendering of an automobile and weave it together with real images so that it appears to be driving through a desert, or down a crowded city street. These advances could also extend to such things as building design, where a prospective client might take a realistic “walk” through a proposed design.

**Photography:** Pictures taken by electronic still cameras could be displayed on a screen or sent over a network for immediate printing at a distant film developer. With computer assistance, photographic-quality images and digital audio might one day be edited almost as easily as words are today.

**Publishing:** Because HDTV allows electronic display, editing and transmission of publication-quality visual material, it will win converts in printing, publishing, advertising, and other businesses where visual presentations are important. In the advertising industry, the electronic processing of HDTV signals is already replacing the editing of 35mm film as a way to produce printed material because of the very significant productivity improvements - despite HDTV’s high initial cost. Electronic editing is also expected to cut working time in the printing environment. Japan’s Dai Nippon Printing, for example, has developed a system that converts HDTV images into digital signals and transfers them directly onto printing plates.

**Movies:** While matching or exceeding the quality of 35mm film, HDTV could bring a host of improvements in movie production and distribution. HD-VCRs could reduce production costs by eliminating film wastage and processing, shortening production time, and allowing image enhancements during editing. And if the video-theater concept takes off, it could lower distribution costs. Movies could be delivered either in compact cassettes - rather than bulky, heavy reels - or distributed instantly to theaters across the country via a satellite and fiber optics network.

**Government:** Many government activities could benefit from HDTV. The FAA has already contracted with Sony for HDTV displays to monitor air traffic. NASA could use HDTV for deep space exploration, remote sensing of the Earth, and for monitoring launches. The military could use HDTV to enhance training simulators, command and control centers, cockpit displays, teleconferencing and aerial reconnaissance - eliminating the delays and logistics inherent in processing film.

Box II

**Alternative Advanced Television Systems**

HDTV is the most advanced television technology currently conceived, but it is not the only one waiting to enter the market. Two other television systems, described below, are also vying for consumers' attention.

**IDTV (Improved Definition Television):** IDTVs use advances in receiver technology to produce a kind of "artificial HDTV". The picture quality is improved by converting from interlaced to progressive scan and by generating additional lines of video information, without requiring any change in the current NTSC signal. The signal received is digitized, processed, stored in memory as a frame, and then displayed 60 times per second, producing a 1,050-line interlaced picture that contains roughly twice the amount of visual information. Special techniques are used to reduce flicker, ghosts, snow and other picture flaws, and to improve color rendition. The screen retains the 4:3 aspect ratio of today's TV sets. IDTVs have been on the market since 1989.

**EDTV (Extended Definition Television):** EDTV follows the precedent set by color television and takes the middle ground between IDTV and HDTV. The transition from B&W to color TV was achieved by adding color information to the NTSC signal, ensuring backward compatibility. Claiming NTSC still has room for improvement, proponents of EDTV want to beef up the current 6-MHz NTSC signals to carry more information. The picture would appear normal on a conventional set, but EDTV receivers would decode and process the additional information to produce pictures with a wider (16:9) aspect ratio and roughly double the resolution of conventional TV sets. Because EDTV would alter the NTSC signal, it would require a new transmission standard and a modest upgrading of existing broadcast equipment. The inefficiency of the NTSC signal, however, means that only modest improvements can be achieved while staying within the current 6-MHz channel bandwidth.

Both Japan and Europe have already adopted EDTV transmission standards. Private Japanese broadcasters began terrestrial broadcasts of EDTV (ClearVision) in August 1989. Satellite broadcasts of the European ED-MAC system started last year. Proponents of EDTV claim that adopting an EDTV system first would speed consumer acceptance of HDTV by allowing broadcasters to upgrade gradually instead of undertaking a wholesale conversion. The FCC, however, has made it clear that it will not select EDTV before deciding on an HDTV transmission standard.

Sources: Choosing the TV of the Future, Technology Review, April 1989; Congressional Budget Office, The Scope of the High-Definition Television Market and Its Implications for Competitiveness, July 1989.
Box III

Proposed Designs for HDTV Receivers

The proposed designs for HDTV receivers respond to the current debate over transmission standards - specifically, whether the transmission system will be augmented or simulcast, and whether there will be one standard or many for the various delivery media. Receivers now envisioned can be classified as closed, multiport, open, or smart. Main features of each are described below.

Closed Receivers: Closed receivers are similar to those used today. They are the simplest of all proposed designs, and are possible only if a single transmission standard is adopted industry-wide by all delivery media. As a result, the picture quality of closed receivers is limited to that possible over the weakest transmission medium. Such receivers have no flexibility to allow future changes in broadcast standards or to allow the addition of other options without substantial modifications. In the near-term, these systems might cost somewhat less than more flexible designs discussed below. The current rapid pace of technological change might, however, make closed systems quickly obsolete - increasing the costs to consumers in the long-term.

Multiport Receivers: Multiport receivers will have multiple jacks or inputs that could accept several incompatible signals: one for terrestrial broadcasts, a second for cable, a third for DBS, and so on. Each delivery medium could thus achieve its full technical potential, delivering a picture quality limited only by its own bandwidth constraints. Multiport receivers could also be used for voice/data/video communications to a limited extent. Such HDTVs would, however, have less flexibility to adapt to future changes or to allow the addition of various options than those described below. The cost of multiport receivers may increase significantly if they must accommodate several radically different transmission standards.

Open Architecture Receivers (OARs): The OAR incorporates digital signal processing and computer technology to create a programmable TV set. Not only can it receive signals in different formats from broadcast, cable, DBS, VCRs and optical fiber, but it can also be interfaced with computers, video games, electronic still cameras, people meters for gauging program ratings and other devices not yet imagined. The OAR's computation section includes a bus structure like that used in personal computers for adding hardware and software. The bus holds electronic cards that can be installed for specialized functions such as image enhancement, freeze frames, viewer-controlled zoom and pan, or other features. Plug-in modules will allow gradual improvements in picture quality as technology evolves. The OAR might thus create new business opportunities for third-party vendors of equipment and services.

Because of OAR's flexibility, creation of a single standard that caters to the lowest common denominator of picture quality no longer remains a constraint. Instead, each medium might adopt a standard that optimizes its performance. Critics argue (Continued...)
Proposed Designs for HDTV Receivers (Continued...)

that OAR would be too expensive and complex to be practical, and that the
challenge of anticipating all transmission standards is daunting. Proponents point
out that the rapid changes in technology demand flexible open systems and that
such systems may ultimately lower overall costs to consumers. Nor are such
systems necessarily complex. A simple channel selector and volume control like
today's can be provided for those who just want to watch TV.

**Smart Receivers:** Smart receivers are the most technologically advanced receivers
currently conceived. They would adjust to a wide variety of transmission standards
by automatically decoding the transmission format. Such sets could even adjust to a
format that varied according to the type of material displayed - scenery with little
motion could be shown at very high resolution, whereas rapid action sports would
emphasize the display of motion. Smart receivers would probably be more expensive
in the near-term due to the high cost of electronics required for such advanced data
manipulation.

Adapted from: U.S. Congress, Office of Technology Assessment, The Big Picture: HDTV &
High-Resolution Systems, June 1990; Choosing the TV of the Future, Technology Review,
April 1989.
Box IV
Stages of New Product Diffusion

Product histories show that new or significantly improved products are not widely adopted immediately following their introduction. Sales are initially slow. When sales reach a market "take-off" point - typically observed to be a few percent of household penetration - they then grow rapidly. After several years of rapid growth, the market begins to saturate and sales flatten to replacement levels. This behavior can be seen in the growth patterns of B&W TV, color TV, and VCR markets (Figure 1, Appendix B). Some products, however, never take off, but the successful ones commonly follow a "diagonal S" shaped growth path which reflects three distinct stages of growth - the innovation stage, an imitation stage and a period of maturation during which sales flatten, decline or disappear.

The innovation stage comprises the early period after a new product is introduced. The product is new; consumers are not familiar with the product; distribution channels are not fully developed so that the product is not widely available in the market; a few venturesome buyers experiment; and, the product may be improved or re-priced based on early consumer responses. As time passes, sales begin to grow fueled from a variety of sources: improved distribution channels, better consumer information about the product, development of supporting products or services and the evolution of a product track record. Many products, of course, never escape this stage and die here.

The imitation stage commences when sufficient favorable product information emanates from the market to both buyers and sellers. Consumers have become aware of key product characteristics through contact with pioneering buyers. Alternative suppliers glean valuable information about the potential of the market. New suppliers enter and vie for market share through product differentiation and/or price competition. This stimulates demand and, as sales grow, production costs and prices decline further as a result of economies of scale, learning curve effects and market rivalry.

Eventually the market matures. Firms may drop out of the market or be absorbed by rivals. Prices stabilize. High penetration rates among potential buyers have been achieved and sales to first time buyers begin to yield to replacement sales as the market driver. The product may become standardized and sell pretty much as a commodity. Absent some new stimulus, the market stabilizes with modest or zero growth. New product or process innovations may either revitalize the market or sound its death knell.

Adapted from: Larry F. Darby, Economic Potential of Advanced Television Products, Prepared for National Telecommunications and Information Administration, April 7, 1988.
### Exhibit 1
Comparison of Conventional TV and HDTV Standards

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Conventional TV Standards</th>
<th>HDTV Standards</th>
<th>Respective Studio Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NTSC (USA/Japan)</td>
<td>PAL/SEACAM (Europe)</td>
<td>MUSE (Japan)</td>
</tr>
<tr>
<td>Scanning lines per frame</td>
<td>525</td>
<td>625</td>
<td>1,125</td>
</tr>
<tr>
<td>Field frequency</td>
<td>59.94 Hz</td>
<td>50 Hz</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Interlace ratio</td>
<td>2 : 1</td>
<td>2 : 1</td>
<td>2 : 1</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>4 : 3</td>
<td>4 : 3</td>
<td>16 : 9</td>
</tr>
<tr>
<td>Baseband signal bandwidth</td>
<td>6 MHz</td>
<td>6 MHz</td>
<td>8 MHz</td>
</tr>
<tr>
<td>Signal bandwidth:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Luminance signal</td>
<td>4.2 MHz</td>
<td>20.0 MHz</td>
<td>20 MHz</td>
</tr>
<tr>
<td>- Color signal</td>
<td>2.0 MHz</td>
<td>12.5 MHz</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Sound</td>
<td>FM (Analog)</td>
<td>FM (Analog)</td>
<td>PCM (Digital)</td>
</tr>
<tr>
<td>Transmission method</td>
<td>Analog</td>
<td>Analog</td>
<td>Analog</td>
</tr>
<tr>
<td>Compatibility with current TV receivers</td>
<td>-</td>
<td>-</td>
<td>Via converter*</td>
</tr>
<tr>
<td>Distribution medium</td>
<td>Note c</td>
<td>Note c</td>
<td>DBSd</td>
</tr>
</tbody>
</table>

---

a. NHK says it can provide converters for about $50 for current TV receivers.
b. MAC is Europe's new satellite-based broadcasting system. TV sets based on current standards (PAL/SEACAM) require a special converter to receive HD-MAC broadcasts.
c. Terrestrial broadcasting, cable, and satellites.
d. Direct Broadcast Satellites. Require a receiving dish at each viewer's home.

### Exhibit 2
Competing Systems for the U.S. HDTV Transmission Standard

<table>
<thead>
<tr>
<th>Entrant</th>
<th>System/Transmission</th>
<th>Scanning Lines/Frame Rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Instrument/MIT</td>
<td>HDTV Digital</td>
<td>1,050 Lines 30 Hz</td>
<td>GI started the digital transmission stampede</td>
</tr>
<tr>
<td>General Instrument/MIT</td>
<td>HDTV Digital</td>
<td>787.5 Lines 60 Hz</td>
<td>Alternative GI/MIT plan would show motion better</td>
</tr>
<tr>
<td>NHK</td>
<td>HDTV Analog</td>
<td>1,125 Lines 30 Hz</td>
<td>Only holdout for analog HDTV transmission</td>
</tr>
<tr>
<td>Philips/Thomson/Sarnoff/NBC</td>
<td>EDTV Analog</td>
<td>525 Lines 60 Hz</td>
<td>Cheapest to implement, but has lowest resolution</td>
</tr>
<tr>
<td>Philips/Thomson/Sarnoff/NBC</td>
<td>HDTV Digital</td>
<td>1,050 Lines 30 Hz</td>
<td>Group says picture will hold up at edge of service area</td>
</tr>
<tr>
<td>Zenith/AT&amp;T</td>
<td>HDTV Digital</td>
<td>787.5 Lines 60 Hz</td>
<td>Odds-on favorite to be the next U.S. transmission standard</td>
</tr>
</tbody>
</table>

**Note:** All HDTV systems offer 16:9 aspect ratio, digital stereo sound and compatibility with existing NTSC receivers.

**Sources:** The U.S. Wins One in High-Tech TV, Fortune, April 8, 1991; Consumer Electronics: Purveyors of Dreams, Economist, April 13, 1991.
Exhibit 3
Projected Worldwide Sales of HDTV Receivers and VCRs

Exhibit 4
Projected U.S. Unit Sales of HDTV Receivers and VCRs

Exhibit 5
Projected U.S. Retail Sales of HDTV Receivers and VCRs

Notes: Sales forecast by EIA were converted into 1988 dollars using EIA's assumed inflation rate of 3.5 percent. The NTIA report values unit sales at two arbitrary price levels: High and Low (receivers at $800 and $400; VCRs at $600 and $300). Only sales under the "High" price scenarios are shown above.

Exhibit 6
Projected U.S. Household Penetration of HDTV Receivers

Note: Household penetration levels for all years of the AEA forecast and last five years of the EIA forecast are author's estimates.

### Exhibit 7
Comparison of U.S. Market Forecasts for HDTV Receivers

<table>
<thead>
<tr>
<th></th>
<th>EIA</th>
<th>NTIA</th>
<th>AEA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year HH penetration reaches 1%</td>
<td>1993-94</td>
<td>1997</td>
<td>1999-2000</td>
</tr>
<tr>
<td>Year of &quot;take-off&quot;(^1)</td>
<td>1993</td>
<td>1997</td>
<td>2000</td>
</tr>
<tr>
<td>Years to &quot;take-off&quot; after introduction</td>
<td>4 - 5</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td><strong>Annual Unit Sales (Millions)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Five years after take-off</td>
<td>8.5</td>
<td>10.5</td>
<td>6.7</td>
</tr>
<tr>
<td>Ten years after take-off</td>
<td>13.1</td>
<td>16.9</td>
<td>11</td>
</tr>
<tr>
<td><strong>Annual Retail Sales (1988 $ Billions)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Five years after take-off</td>
<td>11.6</td>
<td>5.1 - 8.3</td>
<td>5.4</td>
</tr>
<tr>
<td>Ten years after take-off</td>
<td>11.8</td>
<td>6.7 - 13.5</td>
<td>6.6</td>
</tr>
<tr>
<td><strong>Cumulative Unit Sales (Millions)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Five years after take-off</td>
<td>25.4</td>
<td>26.4</td>
<td>24.3</td>
</tr>
<tr>
<td>Ten years after take-off</td>
<td>81.9</td>
<td>96.9</td>
<td>65.8</td>
</tr>
<tr>
<td><strong>Cumulative Retail Sales (1988 $ Billions)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Five years after take-off</td>
<td>38.3</td>
<td>11.5 - 21</td>
<td>24.4</td>
</tr>
<tr>
<td>Ten years after take-off</td>
<td>97.4</td>
<td>38.7 - 77.5</td>
<td>51.6</td>
</tr>
<tr>
<td><strong>Annual Growth in Unit Sales (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First 5 years after take-off</td>
<td>64.8</td>
<td>60</td>
<td>46.3</td>
</tr>
<tr>
<td>Second 5 years after take-off</td>
<td>9</td>
<td>10</td>
<td>10.4</td>
</tr>
<tr>
<td><strong>Household Penetration (%)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Five years after take-off</td>
<td>23.7</td>
<td>23.5</td>
<td>20.7(^2)</td>
</tr>
<tr>
<td>Ten years after take-off</td>
<td>70.9(^2)</td>
<td>80</td>
<td>51.8(^2)</td>
</tr>
<tr>
<td><strong>Receiver Prices (1988 Dollars)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>At introduction</td>
<td>2,500</td>
<td>3,000</td>
<td>4,000</td>
</tr>
<tr>
<td>At take-off</td>
<td>1,925</td>
<td>400 - 800</td>
<td>1,500</td>
</tr>
<tr>
<td>Five years after take-off</td>
<td>1,360</td>
<td>400 - 800</td>
<td>800</td>
</tr>
<tr>
<td>Ten years after take-off</td>
<td>900</td>
<td>400 - 800</td>
<td>600</td>
</tr>
</tbody>
</table>

1. Market is assumed to "take-off" when annual sales reach roughly one million units.
2. Estimated value based on data in various forecasts.

While the more optimistic EIA and NTIA forecasts are fairly close to the faster market penetration of VCR, the AEA forecast practically replicates the growth pattern of color TV.

Sources: Exhibits 4 and 6; EIA Electronic Market Data Book; TV Factbook.
Exhibit 9
Projected Prices of HDTV Receivers and VCRs

Note: NTIA makes no attempt to forecast unit prices. Instead, it assumes two arbitrary price levels (High and Low) to forecast a range in market value of unit sales. "High" unit prices (shown) are twice the "Low" unit prices.

Exhibit 10

Note: Data includes all types of conventional TV receivers, color and monochrome.

Source: Data from EIA Electronic Market Data Book, various years.
Growing number of TV stations and declining receiver prices helped B&W TV achieve high U.S. household penetration very quickly.

Exhibit 12
Color TV Prices, Household Penetration and Growth in Programming

Household penetration of color TV was swift after prime-time hours devoted to color programming increased rapidly beginning in 1963. Note that color TV prices and the price differential between color and B&W sets declined only slowly.

Sources: Development of a U.S.-based ATV Industry, Boston Consulting Group, May 9, 1989; EIA Electronic Market Data Book; TV Factbook.
Exhibit 13
VCR Prices, Unit Sales and Growth of Videotape Rental Stores

*Growth in VCR sales corresponds more closely with the increase in videotape rental stores than with the decline in VCR prices.*

Exhibit 14
Projected Sales of Semiconductors for Advanced TVs

(Data includes HDTV, IDTV and EDTV)

Rapidly increasing consumption of semiconductors in advanced TVs will increase the size of an already large semiconductor market.

Source: Stanford Resources, Inc., San Jose, California.
Exhibit 15
Projected Unit Sales of High Definition Displays

Large-area flat panel displays are expected to become a commercial reality in the late 1990s. Sales should gain momentum by the year 2000.

Source: Stanford Resources, Inc., San Jose, California.
### Exhibit 16
Competing Technologies for HDTV Flat Panel Displays

<table>
<thead>
<tr>
<th>Technology</th>
<th>Companies</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Matrix Liquid-Crystal Displays</td>
<td>Sharp, Hitachi, Matsushita, Sarnoff Labs, Toshiba/IBM, Magnascreen, Ovonic</td>
<td>When a transistor at each pixel is turned on, it causes a liquid crystal to twist, allowing light to pass through</td>
</tr>
<tr>
<td>Plasma Technology</td>
<td>Photonics, NHK, Matsushita, Sharp, Thomson, Hitachi</td>
<td>An electric current to each pixel causes a gas to glow. The light then stimulates a phosphor coating to produce the image</td>
</tr>
<tr>
<td>Electro-Luminescence (EL)</td>
<td>Planar Systems, Sharp, Hitachi</td>
<td>An electric current causes the phosphor coating at each pixel to glow</td>
</tr>
<tr>
<td>Vacuum Microelectronics</td>
<td>Coloray Display, Thomson</td>
<td>Unlike a conventional TV, in which a single electron beam sweeps back and forth, this technology uses a microscopic electronic source, or cathode, for each pixel</td>
</tr>
<tr>
<td>Deformable Mirrors</td>
<td>Texas Instruments</td>
<td>A projection system which relies on tiny movable mirrors on a sheet of silicon. The angle of reflection controls each pixel</td>
</tr>
</tbody>
</table>

Large price differentials between HDTV and other types of receivers may be a strong enough incentive for most consumers to settle for less advanced versions of TV.

**Exhibit 18**

**Products As % of Consumer-Electronics Industry's Total Sales**

*Major breadwinners for the consumer electronics industry have reached maturity. The industry needs another blockbuster product to avoid hard times ahead.*

**Sources:** Japanese Ministry of International Trade and Industry; EIA Electronic Market Data Book.
Exhibit 19
Growth Rate of Consumer Electronics Industry

Though working on numerous other products, the industry is banking on HDTV to fuel its future growth.

### Exhibit 20
Selected HDTV Technology Development Efforts by Japanese Firms

<table>
<thead>
<tr>
<th>Firm</th>
<th>Cameras</th>
<th>Recording</th>
<th>Transmitter/Receiver</th>
<th>Displays</th>
<th>Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tube</td>
<td>CCD</td>
<td>Optical</td>
<td>Digital</td>
<td>Analog</td>
</tr>
<tr>
<td>Cannon</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Fujitsu</td>
<td>-</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td></td>
</tr>
<tr>
<td>Hitachi</td>
<td>R</td>
<td>-</td>
<td>R</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Ikegami</td>
<td>C</td>
<td>R</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Matsushita</td>
<td>R</td>
<td>R</td>
<td>-</td>
<td>-</td>
<td>R</td>
</tr>
<tr>
<td>Mitsubishi</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>C</td>
<td>-</td>
</tr>
<tr>
<td>NEC</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>-</td>
<td>R</td>
</tr>
<tr>
<td>Pioneer</td>
<td>-</td>
<td>-</td>
<td>R</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sanyo</td>
<td>R</td>
<td>R</td>
<td>C</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>Sharp</td>
<td>R</td>
<td>R</td>
<td>R</td>
<td>-</td>
<td>R</td>
</tr>
<tr>
<td>Sony</td>
<td>C</td>
<td>R</td>
<td>C</td>
<td>-</td>
<td>R</td>
</tr>
<tr>
<td>Toshiba</td>
<td>-</td>
<td>R</td>
<td>R</td>
<td>-</td>
<td>R</td>
</tr>
<tr>
<td>JVC</td>
<td>R</td>
<td>R</td>
<td>C</td>
<td>-</td>
<td>R</td>
</tr>
</tbody>
</table>

**Key:**
- R (Research); C (Commercializing); CCD (Charge-Coupled Device); CRT (Cathode Ray Tube); SS (Solid State); FPD (Flat Panel Display).

**Notes:**
- SS displays are typically LCDs or deformable membranes. FPDs include LCD and plasma panels, but other types are also being developed. Many other developments, such as studio or transmission equipment, are not listed above.

**Source:** U.S. Congress, Office of Technology Assessment, The Big Picture: HDTV & High-Resolution Systems, June 1990.
### Exhibit 21
Projects and Participating Firms in Europe's Eureka-95

<table>
<thead>
<tr>
<th>No.</th>
<th>Project</th>
<th>Project Leader</th>
<th>Participating Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fundamentals of picture and sound</td>
<td>CCETT</td>
<td>BBC, HHI, IBA, ITVA, Philips, RAI, Thomson</td>
</tr>
<tr>
<td>2</td>
<td>Production standards</td>
<td>Thomson</td>
<td>BBC, CCETT, Dortmund Univ., IBA, ITVA, Philips</td>
</tr>
<tr>
<td>3</td>
<td>Studio equipment</td>
<td>Bosch</td>
<td>Angeneieux, Barco, Heimann, Philips, Quantel, Rank, Schneider, Thomson</td>
</tr>
<tr>
<td>4</td>
<td>Transmission</td>
<td>IBA</td>
<td>BBC, British Telecom, CCETT, DBP/FTZ, Graetz, Nokia, Philips, Thomson</td>
</tr>
<tr>
<td>5</td>
<td>HD-MAC encoding/decoding</td>
<td>Philips</td>
<td>BBC, CCETT, DBP/FTZ, Fuba, Dortmund Univ., IBA, ITT, RAI, Swetel, Thomson</td>
</tr>
<tr>
<td>6</td>
<td>Display standard and up-conversions</td>
<td>BBC</td>
<td>Dortmund Univ., Grundig, ITVA, Philips, Thomson</td>
</tr>
<tr>
<td>7</td>
<td>Receivers</td>
<td>Ferguson</td>
<td>Graetz, Grundig, Intermetall, Nokia, Oceanic, Philips, Salora, Seleco, Thomson, Videocolor</td>
</tr>
<tr>
<td>8</td>
<td>Carriers (VCRs, laser disc players, etc.)</td>
<td>Philips</td>
<td>Grundig</td>
</tr>
<tr>
<td>9</td>
<td>Program Material</td>
<td>RAI</td>
<td>BBC, Captain Video, ITVA, SFP</td>
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<td>10</td>
<td>Bit-rate reduction</td>
<td>Thomson</td>
<td>BBC, British Telecom, DBP/FTZ, Philips</td>
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Cable television is poised to be a major contender for distribution of HDTV programming to consumers.

Sources: Electronic Market Data Book, EIA; Television Digest.
Appendix A

Shortcomings of NTSC Television

In May 1941, the FCC adopted the NTSC transmission standard for monochrome television. In 1953, the standard was modified to add color; in 1984, it was modified again to add stereo sound. Although NTSC television has been a remarkable success, certain defects limit its audio and video quality. Some of these defects are inherent, but others are the result of adding color information to the transmitted signal without increasing its bandwidth.

Interline flicker is seen along the horizontal borders of objects. Because NTSC interlaces 30 pairs of scanning lines per second, any line representing the horizontal edge of an object flashes on the TV screen only half the time, or at a rate of 30 frames per second, well below the rate at which the eye fuses discrete, repetitive images. So the edge flickers irritatingly to the eye.

Line crawl is evident in places where the brightness varies rapidly. In NTSC's interlaced scanning process, a new line appears on the screen 1/60th of a second after the line above (or below) it. The human eye first interprets the alternate fading of the two lines as constant upward (or downward) motion. But once the brain locks onto the pattern, it compensates by averaging the pair, reducing the perceived resolution of the picture.

Vertical aliasing is seen in watery or wavelike patterns like those on watered silk or a tweed jacket. Due to the interlaced scanning process, if this kind of pattern is created in one field, it is canceled out by a similar pattern in the next field. The human eye cannot adequately integrate the two fields, and instead sees an unnatural cluttering effect wherever the pattern occurs.

Large-area flicker is visible within bright images and is more obvious to viewers who are seated less than the recommended distance from the screen. Studies have confirmed that the eye can perceive variations in brightness at frequencies above the 60-Hz NTSC field rate. Perception of flicker varies directly with the scene brightness.

Static raster is more apparent on larger TV displays where viewers can make out the individual scan lines of a frame. Better large-screen displays minimize or compensate for this effect, but it can be virtually eliminated by increasing the number of scan lines per frame.

Cross color is perceived when a scene contains a detailed pattern like a striped shirt or a tweed jacket. The image degenerates into rainbow colors creating a bizarre color pattern that does not resemble the area of detail. The defect occurs because the NTSC signal mixes the brightness and color information in the same composite baseband spectrum.
Cross luminance or dot crawl refers to the dot pattern that crawls around the picture, making the TV screen look like an ant's nest. This defect also stems from the structure of the NTSC signal which mixes color and luminance signals in such a manner that they interfere with each other.

Other Defects: NTSC also has several other defects. Research shows that viewers obtain a greater sense of realism and involvement, as well as an illusion of depth, not just from a better picture but from a wider display, one that is a better match to the human field of vision than the compressed 4:3 aspect ratio of today's television. The cinema's 2:1 aspect ratio comes closer.

The horizontal and vertical resolutions of NTSC, its color fidelity and its range of brightness were all limited in order to meet bandwidth constraints. As a result, NTSC produces pictures that are less sharp and bright than in movie theaters, while its audio quality is poor compared to that of compact discs.

NTSC is very susceptible to a variety of transmission problems - ghosts, snow (noise), interference from other stations, etc. NTSC also has a tendency to switch between different colors and is often dubbed as "Never Twice the Same Color". Because of these problems, today's TV audience views a picture far worse than what is theoretically possible, and might easily mistake a studio quality NTSC picture for HDTV.

Finally, NTSC does not use the available spectrum efficiently: more information can be packed into the existing 6-MHz channel bandwidth; and large amounts of spectrum are unusable - every other channel in VHF and typically 5 out of 6 channels in UHF are not used because of interference problems. It was precisely because of NTSC's poor use of bandwidth that monochrome TV could be turned into a compatible color system. Today, EDTV proposals hope to exploit this inefficiency even further to provide higher resolution and a wider screen without requiring additional bandwidth.

Appendix B
Commercialization of NTSC Television

It appears that there are significant barriers to widespread and rapid consumer acceptance of HDTV receivers. These barriers, however, are not in essential respects qualitatively different from those confronted initially by the current TV receivers. Yet, color TV, which was replacement for an existing technology in the mid-1950s as HDTV is today, has become the most successful consumer product ever introduced. This appendix analyzes the forces that shaped the development of both B&W and color TV markets.

Commercialization of Monochrome TV
After 15 years of development since the first demonstration of a practical television system in England, monochrome TV was introduced in the U.S. in 1941. The FCC adopted the NTSC standard in May 1941 and authorized public television service beginning July 1, 1941. NBC began regular TV broadcasts over WNBT (New York) - the first commercial TV station - offering 14 hours a week of programming. By the end of 1941, there were 6 commercial stations in operation, and two manufacturers were producing TV sets. However, only about 10,000 sets were sold when World War II put an end to further commercialization of TV. All TV-related activity was halted in April 1942.

After the War, TV sets were reintroduced in late 1946 amid optimistic sales forecasts. But before monochrome TV could move into high gear, it faced another problem. In 1946 CBS petitioned for commercialization of color TV using frequencies different from those then assigned to monochrome TV. RCA and its allies, which included Philco and DuMont, wanted TV to get off to a fast postwar start in the VHF band. But the CBS camp, which included Zenith, wanted TV to be assigned to the UHF band. It was not until this uncertainty was removed, when the FCC denied the CBS petition in March 1947, that the industry was encouraged to proceed on a large scale. By yearend, seventy manufacturers were making TV sets, and 12 stations were on the air.

Despite other problems discussed later, monochrome TV's market penetration after 1947 was unprecedentedly swift. By 1949, demand for TVs was running 2 years ahead of even the most optimistic projections that had been made in 1946. Sales went from a mere 179,000 units in 1947 to 7.4 million units in 1950; household penetration increased from almost zero to 9% during the same period (Figure 1). Sales fell 28% in 1951, but recovered the following year, reaching 7.7 million units in 1955 and then declining modestly in the late 1950s. By the end of 1954, the year color TV was introduced, almost 56% of American homes owned monochrome TV sets.
By 1959, there were almost 50 million monochrome receivers in use; over 85% of households had at least one set; 70% of unit sales consisted of replacement sets; and the market was considered by most to have reached maturity. Monochrome TV, in short, enjoyed unparalleled success. Discussed below are factors that influenced the development of the monochrome TV market.

**New Product Concept**
Television was an entirely new product. Nothing like it had existed before. For the first time, TV allowed people to watch the human conflict dramas in their own living rooms. It was the overwhelming consumer response to this new concept in home entertainment that made monochrome TV a huge success very quickly. Nothing could withstand TV's onslaught during its early years. Movies, theaters, radio and nightclubs all suffered as TV caught on the public fancy. Radio listening dropped in television cities and movie theaters closed in waves. In 1951 alone almost all TV cities had a 20% to 40% drop in movie attendance, whereas in non-TV cities movie attendance remained high or even grew.

**Favorable Economic Climate**
The postwar era was a period of rapid growth economy, with enormous pent-up demand for consumer durables. TV sales greatly benefitted from this healthy economic climate. Except for occasional slowdowns and small material shortages during the Korean War years starting in 1950, economic growth continued strongly until the late 1950s.

**Availability of Programming**
While there were still only 6 TV stations after the War, new stations were built quickly. By 1948 there were 36 stations on the air and about 70 under construction. But, interference between nearby stations became a serious problem. On September 30, 1948, the FCC declared a freeze on licensing of new TV stations in order to reconsider the frequency allocations. The freeze lasted until April 1952, prolonged by the Korean War. Despite the slowdown caused by the freeze, there were 377 stations in operation by mid-1954 and over 90% of U.S. homes could receive TV signals.

**Declining Receiver Prices**
TV set prices dropped rapidly for two reasons: competition and improvements in manufacturing. Numerous firms had rushed to make TVs after 1947. The number of firms increased from 70 in 1947 to 140 in 1950. By 1950 there was overproduction, and the resulting rivalry forced 30 firms to abandon TV manufacturing in just one year. Panic selling caused prices to fall, and this induced many manufacturers to sacrifice quality by using cheaper components and ignoring styling. The adverse public reaction caused inventories to pile up and prices fell further. Competition remained fierce through 1956, pushing prices down. By then, another 59 manufacturers had fallen by the wayside.

In the early years, TVs were sold through many diverse outlets. This not only gave TV sets an excellent market exposure, but also led to widespread
discounting at the retail level. Competition among distributors increased in the 1950s, forcing many to drop TV sets. Efforts to curtail discounting were not particularly successful. By the late 1950s, TVs were increasingly sold directly by manufacturers to large discount stores and national chains, whose aggressive retailing practices brought consumers even lower prices.

Most major firms started using printed circuit boards (PCBs) in the mid-1950s. Components could be cheaply inserted into PCBs and all the components soldered at once. At least one company, Admiral, tried using automatic insertion of components onto PCBs, but had only modest success due to the complexity of TV circuits. Though hand-insertion remained the method used industrywide in the 1950s, the switch to PCBs lowered manufacturing costs.

**Set Reliability**
Initially, TV sets broke down quite often and consumers were extremely concerned with repair service. After 1955 set reliability improved considerably, mainly due to reduced failures of the picture tube and increased use of transistors. The price of an RCA service contract, for example, dropped from $100 in 1950 to $69.95 in 1955. Servicemen frequently played an important role in the purchase decision, as consumers often asked them about the quality of a specific brand. Despite its higher than industry-average prices, Zenith, for example, snatched the top market position from RCA in 1959 by designing its TV chassis for easy servicing, by hand-wiring and hand-soldering all connections for greater reliability, and by stressing quality in its manufacturing and advertising. This strategy helped Zenith win the crucial support of servicemen, who were still unfamiliar with printed circuits and preferred working on hand-wired sets.

**Product Improvements**
Several improvements were made in monochrome TV during its early years. The quality of the picture was continually improved. Early 10" round picture tubes were replaced by 12 1/2" screens in 1949. After Corning's innovations in bulb-making technology, 17" and 21" rectangular screens were introduced in the early 1950s. TVs also became more compact as a result of the 110-degree deflection angles on these new screens. The original electronic components in TVs were vacuum tubes. By the late 1950s, several companies had started replacing the vacuum tubes with transistors. Though transistors were more expensive initially, their use improved reliability.

**Commercialization of Color TV**
While experiments on color began earlier, the first practical color TV system was demonstrated by J. L. Baird in 1928. By 1950, two fundamentally different color TV systems that worked within the 6-MHz channel bandwidth were vying for FCC's approval. The CBS system used a rotating disk to produce brilliant, realistic colors, but was incompatible with the rapidly growing base of B&W sets. CBS contended that B&W sets could be modified for about $25 to receive
color broadcasts in monochrome. The all-electronic RCA system, on the other hand, was compatible with B&W sets, but produced poor quality colors, required very complex reception and transmission equipment, and was much more susceptible to interference than the existing monochrome system.

The FCC was thus faced with a dilemma: whether to approve CBS's superior but incompatible system or RCA's compatible but inferior system. Believing that flaws in the RCA system were inherent and that any further delay in introducing an incompatible system would greatly increase conversion costs, the FCC approved the CBS system in October 1950. Many in the industry had pleaded for more time to refine the all-electronic compatible system, and were disappointed by the FCC decision. RCA carried its opposition all the way up to the Supreme Court, but lost the case in May 1951. In June, CBS began color broadcasts, and even made TV sets in subsequent months. But refusal of the Office of Defense Mobilization to allocate essential materials and components due to the Korean War forced CBS to terminate its operations in October 1951.

In June 1951, the industry set up a second NTSC to study color standards. During the next two years, the NTSC conducted extensive technical work and developed an all-electronic, compatible color system. On December 17, 1953, when more than 21 million B&W sets were already in use, the FCC reversed its earlier decision and approved the NTSC system. Public broadcasts were authorized starting January 22, 1954.

Immediately after the FCC decision, color TV was introduced amid optimistic sales projections. For several reasons, however, sales languished until the 4th quarter of 1961 and did not really take off until 1962. After the household penetration reached 1% in 1962, consumer purchases escalated rapidly and, in the first 4 years thereafter, sales grew 84% every year. Though consumers bought 5 million units in 1966, it was not until the 1970s that color TV became a common household fixture. Even as late as 1970 just 37.3% of U.S. homes had color sets. Two years later the figure finally passed the 50% mark, and by 1985, color TV had penetrated 91.5% of households (Figure 1). Described below are the main events that shaped the development of the color TV market.

**The 1950s**

In 1954, a number of manufacturers rushed into the market with great expectations. Annual sales of color TV were forecast to reach 1 million units by 1955. But consumer response proved to be dismal. Only about 25,000 color sets were sold in the first two years. Soon thereafter all color TV manufacturers withdrew from the market except RCA and Packard Bell. Of the two networks broadcasting some programs in color, CBS ceased doing so, leaving NBC alone.

RCA continued to push color TV, however. NBC, then owned by RCA, aggressively added color programming - at a loss. RCA's service arm held clinics all across the country to train servicemen to repair color sets. RCA engaged in extensive dealer promotions, demonstrations and point-of-sale
gimmicks. RCA made private-label color TVs for those few firms that wanted to sell them. Sticking to its long-held policy, RCA also continued to license its patent rights to other firms, both domestic and foreign. Despite all this, sales crept along to the end of the decade and only 380,000 color sets were sold during the first six years. By 1960, RCA had invested $130 million in color TV (in contrast, its comparable investment in B&W TV was $50 million). The early growth of color TV was dismal for a variety of reasons.

**Lack of Programming:** There were just 68 hours of color broadcasts during all of 1954. Although NBC vigorously promoted color shows, there were still only 25 local TV stations broadcasting color out of 545 nationwide in 1959. Color programs were much more expensive to produce than B&W shows, but had almost no impact on a network's audience share. The installed base of color sets was still too small and networks were the only source of programming. As a result, ABC and CBS sat out the 1950s and color programming increased only slowly.

**High, Sticky Prices:** In 1954, color set prices ranged from $500 to $1,000 ($2,200 to $4,400 in 1988 dollars) compared to $200 for an average B&W set. Color set assembly was more complex than that of B&W sets because it involved over 3 times as many parts. Though discounting by dealers was common, these introductory prices remained unchanged for almost 10 years as there was practically no competition, and no technical breakthroughs were achieved to lower manufacturing costs.

**Poor Product Quality:** Color TV eventually became a hit with consumers because it offered a big improvement over monochrome television: Mud and blood were indistinguishable in black and white; in color, blood was blood. But the early color sets had poor and dim picture quality, and broke down quite often. Consumer purchases increased only after picture quality and set reliability began improving in the early 1960s.

**Unfavorable Economic Climate:** Also instrumental in the slow early growth of color TV was the fact that the first 6 years included 3 years of general economic recession - one year of moderate recession and two years of more severe economic conditions. As consumers deferred major purchases, sales of color TV were especially hurt since color sets were expensive.

**Lack of Competition:** In 1959, there were just 3 color TV manufacturers - RCA, Packard Bell and Admiral. While several firms initially made color TVs and exited after 1955, many major firms (including Zenith, GE and CBS) held back from color altogether. Some waited for the development of a new, less expensive picture tube; others were conducting their own research; while still others considered the color TV market too small to make entry worthwhile. This skepticism among manufacturers had several adverse consequences. Lack of competition kept prices high and limited publicity; many dealers refused to
carry color TV, further limiting its exposure; and, above all, consumers remained skeptical about the future of color TV.

**Slow Technical Progress:** Picture tube was the most expensive component of a color set. Many also regarded it as the most complex and difficult consumer good ever to be manufactured. Since RCA had an armlock on this critical technology, its 2½" round shadow-mask tube was the only available option for over a decade. Until the early 1960s, RCA was the only company that had spent the millions of dollars necessary to tool up for mass production of color tubes. The leading alternative, the Chromatron tube, remained under development for many years by a subsidiary of Paramount Pictures, but never reached commercial production.

**1960**
RCA captured 80-95% share of the color set market, and initiated a heavy advertising and promotional campaign on color TV. NBC greatly increased its color broadcasts, but there were still only 32 hours per week of color programming. An observer commented: "About all that is holding back an enormous increase in available color programs, in fact, is the attitude of NBC's two big network rivals."

Due to improved set reliability, an RCA service contract for a year had dropped to $70 from the $140 that it had been earlier. RCA's cheapest color set retailed for $495, but RCA chairman, David Sarnoff, insisted, "There is nothing on the horizon which promises significantly lower priced or better color TV."

Interest in manufacturing color TVs increased in 1960. Emerson Radio resumed production, and at least 5 other manufacturers approached RCA about buying color picture tubes. Major manufacturers continued research in color TV, but were still awaiting a real surge in consumer demand and letting RCA bear the brunt of promotional efforts. RCA, the only color tube manufacturer, continued to build tubes for its three competitors, and licensed Matsushita and Toshiba to use its picture tube patents.

**1961**
More color broadcasting was helping sales of color sets. NBC was planning to double its color broadcasting hours. In addition, local color programming was being increased in many major cities. CBS had only a sporadic color schedule; ABC still had none at all.

While RCA's portable set sold for $495, its main color model (and those of others) retailed for about $600, which was triple the average industry price for B&W sets. RCA and Motorola independently announced the development of new rectangular picture tubes that produced brighter pictures and were 5" shorter than the 21" round RCA color tube then on the market.
In February 1961, Zenith entered the color TV market. Zenith sets offered increased picture brightness, an easy-to-service horizontal chassis design, and hand-wired circuits for greater reliability. Zenith’s entry was considered a major breakthrough because many dealers were reluctant to handle color TV as long as the largest TV producer avoided it. Most other major firms, including GE, also began making color TVs in 1961 and, by yearend, there were 10 color TV manufacturers. New entrants in the color TV market increased advertising and publicity in 1961, boosting industrywide sales.

1962
Color TV finally entered the mass market. Sales reached 438,000 units, triple that in the previous year. RCA, now operating at full capacity, stated that if the supply of tubes, which still only RCA made, had not been limited, over 500,000 sets could have been sold. The impressive showing of color TV in 1962 was attributed largely to the changed consumer attitude toward color. The change apparently stemmed from more reliable, trouble-free receivers, relatively low-cost service contracts and an improved picture tube that was 50% brighter than earlier models. NBC increased its color broadcasting hours, and ABC and CBS both began color transmissions.

1963
For the first time since RCA began pushing color TV in 1954, every major TV manufacturer had or was entering the field. By yearend, there were 43 color TV manufacturers, and RCA’s market share had dropped to 65 percent. Competition led to the first price cuts in color TV. In June, Admiral announced a 21” set for $400, and GE replied with a lesser cut to $450. RCA’s lowest priced set stayed firm at $495. Retail price-cutting had been prevalent well before the manufacturer price cuts, and color TV was being increasingly handled by discount stores. Motorola and National Video started producing Motorola’s new 23” tube; Zenith and Sylvania began making 21” round tubes.

1964
Sales reached 1.4 million units, 88% higher than in 1963. As early as January, however, demand for RCA’s color tubes was exceeding production. RCA was selling color tubes to more than 24 other firms - up from 15 a year earlier. Many said they could not get enough tubes from RCA. Despite tube shortages, RCA dropped prices on color TVs by $130 to $150, and other major producers soon responded with similar cuts. RCA did not cut its price on color tubes, however. Magnavox, Motorola and Admiral alleged that RCA was overcharging them for its 21” round tube, whose price had stayed at $98.50 for 10 years. In 1964, RCA also introduced its first major improvement in picture tube design: a 25” set based on its new rectangular tube. During 1964 the first Japanese color TVs began arriving in the U.S. under the guise of Sears labels.

1965
By the fall of 1965 both CBS and NBC had become virtually all-color networks; ABC did so in the following year. Rectangular picture tubes had a major
impact on sales, which climbed to 2.7 million units in 1965. For the first time, color TV dollar sales exceeded B&W sales despite strong B&W sales. All tube plants were operating virtually around the clock, but color tubes were still in short supply. By yearend, waiting lists were common for American-made color sets, and some manufacturers had raised prices slightly on color sets. Anticipating surging sales, both RCA and Zenith undertook multi-million dollar programs to expand their set and tube production capacity. RCA's market share in color TVs was now 34%, down from 65% just two years ago.

1966
By 1966, almost all major TV producers had jumped into color picture tube production. The industry's output of color tubes had increased from 2.45 million units to 6.4 million units in just one year. But with color TV demand running far ahead of supply, there was a critical shortage of tubes as well as of labor and other components such as copper and cabinets. In September, Zenith and Motorola raised color set prices by an average of 3% citing the various shortages as a reason; RCA and Admiral soon followed. In the 4th quarter, however, sales growth slowed below expectations, forcing layoffs in some firms. Tight money and higher interest rates were blamed.

In 1966, RCA pioneered the use of ICs in TV sets. Many U.S. retail chains signed on Japanese manufacturers to produce private-label color TVs. For example, Montgomery Ward took on Sharp, while J.C. Penney signed on Matsushita. Japanese color TVs were not superior technologically, but enjoyed lower manufacturing costs, primarily due to cheaper labor.

1967
There was a sharp slowdown in the growth rate of color TV sales. Unit sales grew only 11% compared to 86% in the previous year. This resulted in inventory build-up, price-cutting and layoffs. Color tube prices fell as well. Japanese color TV imports were nearly 350,000 units, most of which were private-label sets and small-screen portables.

1968
Color TV sales reached 6.2 million units. There was no picture tube shortage, and tube prices dropped slightly. Sony introduced an improved new color picture tube, the Trinitron, in 1968 after an aborted effort with Paramount's Chromatron tube some years earlier. Major producers, including RCA and Zenith, introduced their first hybrid chassis (partly transistorized), while Motorola launched the first U.S. all-transistor color TV, named Quasar. Average factory prices held close to the $362 figure for 1967. This was attributed to selected price increases by some producers and the higher manufacturing cost of solid-state color TVs.

1969
Government efforts to cool the economy and slow down inflation resulted in extremely tight money supply, and with it lower sales of consumer durables.
Fourth quarter sales of color sets were sharply lower, and overall sales showed the first dip since color TV took off in 1962. A major factor affecting all U.S. manufacturers was increased imports of Japanese color sets, which rose to 880,000 units in 1969. By yearend, there were 20 U.S. TV manufacturers, down from 43 in 1963. Several U.S. producers introduced new picture tubes with greater sharpness and contrast. In Japan, Hitachi became the first company in the world to convert its entire color TV line to 100% solid-state design. Because 100% solid-state TVs used less than 50% the power of equivalent vacuum tube sets, the switch to solid-state eventually made TVs much more reliable.

1970
Due to recession, color TV sales fell to 5.3 million units, down 14% from the previous year. On January 1, RCA cut prices on color tubes by 12 to 16 percent. Recognizing industry overcapacity, RCA also consolidated its color tube operations. In July, RCA introduced a 110-degree tube which was about 4" shorter than 90-degree tubes. In addition, about 75% of RCA's circuitry was solid-state, and sets carried a 1 year warranty as opposed to the 90 day warranty on older models. In 1970, all major Japanese firms followed Hitachi's lead and converted completely to 100% solid-state models. Consumers were by now fully sold on solid-state; their favorable response to Japanese TVs surprised all U.S. manufacturers. At the time, Motorola was the only U.S. producer with a 100% solid-state color set.

1971
Color TV sales recovered strongly, aided by the decline in interest rates. The use of solid-state chassis was rising among U.S. firms. RCA introduced the XL-100 series, the industry's broadest line of 100% solid-state large-screen sets. The switch to solid-state slowed the decline in prices, however. Average factory price was around $332 early in 1971. Major product innovations of 1971 included a low-cost remote control and an all-electronic tuner.

1972
Color sales reached 8.8 million units and exceeded B&W TV sales for the first time, attributed to increased penetration of households, improved picture quality, rapid cable TV growth and low prices due to competition. The trend toward solid-state continued. A major development was the in-line color picture tube. The in-line tube used a single gun to fire the three beams. This resulted in greater reliability, less need for adjustments, smaller size and lower cost. Many firms also started using the slot-mask/vertical stripe system, introduced by Sony in 1968. The vertical grill let more electrons hit the screen, producing a brighter picture. In 1972, Zenith became the first U.S. company to attempt plant-wide automation, and Sony started building a color TV assembly plant in San Diego - marking the beginning of direct Japanese investment in the U.S.

1973
Color TV sales reached their highest level ever. More than 10 million sets were sold. Almost 58% of U.S. homes now had at least one color TV, and 60% of the
sales in 1973 were accounted for by replacement sets. For the first time RCA lost the top market position in color TV to Zenith, mainly due to the relatively inferior quality of its sets.

**Post 1973**

Because of the worldwide economic slump created by the 1973 OPEC Oil Crisis, sales of color TV took a sharp dive after 1973 and fell to 6.7 million units in 1975. Color TV was among the hardest hit consumer items, but sales had climbed back to 10.5 million units by 1978. Improved product quality (due to 100% solid-state designs and brighter picture tubes), rapidly declining prices (due to fierce competition and process improvements), and diversity in programming (due to strong cable TV growth) were the key reasons for color TV’s growth during this period. In the 1970s, keen competition from the Japanese also resulted in demise of the U.S. TV manufacturing industry. Most U.S. firms either exited the TV business or sold out to a foreign company.

After 1975, the growth of color TV was remarkably steady, and was interrupted only by periodic economic recessions. Booming economy, low prices, and a wide array of programming choices (from VCRs, cable TV, satellites) led to unprecedented sales of color TV in the 1980s. Since 1988, consumers have purchased more than 20 million color TVs every year.

**Process Improvements**

While color TV prices came down only slowly during the 1960s, they began declining more rapidly in the early 1970s. Reductions in component counts and labor cost due to an increased use of solid-state technology and automation in manufacturing were the key reasons. See Figure 2.

Automatic insertion was the most significant process technology innovation since the adoption of printed circuit boards. Developed in the mid-1950s, the early machines were widely used in radio production, but were incapable of handling the more complex TV circuit boards. As machines improved in the 1960s, several U.S. firms experimented with a few units, but without success. Because each machine could handle only a specific shape and size, a series of machines was required to insert all the varied components on a circuit board. Whenever one machine jammed the entire line was held up. In addition, many of the circuit board designs were simply not amenable to automatic insertion.

It was not until 1969 that the first Variable Center Distance (VCD) machine was developed. This could handle any sequence of components and was easily programmed and controlled via a computer. It could therefore insert nearly all components on a circuit board. Some U.S. manufacturers experimented with VCDs, but they still had not learned how to design to take advantage of automation. At this time the switch to solid-state also required constantly changing designs and as a result no economies were achieved. It was only toward the late 1970s that U.S. firms began adopting more automation due to the increased reliability this led to.
The Japanese were very successful in meshing circuit board designs with the needs of automation. In 1970, all Japanese color set manufacturers switched to 100% solid-state chassis. Subsequently they were able to reduce component counts through extensive use of ICs, early use of in-line tubes and single circuit board designs. Labor cost savings were achieved through reduced component counts and use of automated insertion and testing. By 1975, nearly 80% of all components in Japanese sets were being inserted by machine. In contrast, use of more labor intensive multiple circuit boards and modules was prevalent in the U.S. because they were easier (and less expensive) to service.

The switch to solid-state and automated production also increased reliability. This was improved even more by the Japanese practice of extensive pre-testing of components. Increased reliability allowed the Japanese to switch to single circuit board designs because service costs were not nearly so important as the set rarely failed. Single circuit boards further cut component counts.

Figure 1
Unit Sales & Household Penetration of B&W TV, Color TV and VCR

Sources: EIA Electronic Market Data Book; TV Factbook.
Increased use of solid-state circuitry and automatic insertion equipment in the early 1970s led to major reductions in electrical parts and assembly hours, and, hence, to significantly lower color TV prices.

Source: Data from Ira C. Magaziner and Robert B. Reich, Minding America's Business, Random House, 1983.
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